TWO-PHASE PRESSURE LOSSES IN VALVES AND FITTINGS

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Master of Science in Chemical Engineering

By

Robert McKinlock Sharp

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TWO PHASE PRESSURE LOSSES IN VALVES AND FITTINGS

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The author also wishes to express his appreciation to the Crane Company for their generous donation of all the valves and fittings studied in this investigation.

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NOMENCLATURE

A	cross-sectional flow area, ft.^{2}
D	pipe diameter, ft.
D_{TS}	pipe diameter of test section, ft.
f	friction factor as defined by Nikuradse equation, dimensionless
f_G	superficial friction factor for gas phase calculated from Reynolds number, Re_G, dimensionless
f_L	superficial friction factor for liquid phase calculated from Reynolds number, Re_L, dimensionless
g_c	conversion factor, 32.2 ft. lb.mass/ sec.^{2} lb. force
L	length, ft.
P	pressure, lb. force/in.^{2}, or in.Hg.
Q_L	flow rate, GPM.
Re_G	superficial Reynolds number of gas phase based on inside pipe diameter, dimensionless
Re_L	superficial Reynolds number of liquid phase based on inside pipe diameter, dimensionless
T_G	temperature of gas phase, °C
T_L	temperature of liquid phase, °C
W_G	gas flow rate, lb. mass/sec.
W_L	liquid flow rate, lb. mass/sec.
X	square root of the ratio of the pressure drop for the flow of liquid alone to the pressure drop for the flow of the gas alone, dimensionless
μ_G	viscosity of gas phase, lb. mass/ft. sec.
μ_L	viscosity of liquid phase, lb. mass/ft. sec.
ρ_L	liquid density, lb. mass/ft.^{3}
Φ_{LTT}	parameter used by Lockhart and Martinelli (1), the square root of the ratio of the two-phase pressure drop per unit length

to the pressure drop per unit length of the liquid phase (subscript L) flowing alone in the pipe, dimensionless. The subscript TT denotes that both the liquid and gas phases are turbulent as defined in reference (1).

Ψ	single-phase equivalent length multiplying factor as developed in this thesis, dimensionless
$\Delta P_{TP\text{-}EXP}$	experimental two-phase pressure drop, in. Hg.
$\left(\frac{\Delta P}{\Delta L}\right)_{TP\text{-}MART}$	two-phase pressure drop per unit length calculated by correlation of Lockhart and Martinelli (1), psi./ft.
L/D	ratio of length to diameter of pipe or method used to express length equivalent of valve or fitting in regard to causing pressure loss, dimensionless
$(L/D)_{TS}$	ratio of length to diameter of pipe for test section, dimensionless
$(L/D)_{V}$	ratio given for valve studied

TWO PHASE PRESSURE DROP IN VALVES AND FITTINGS

Robert McKinlock Sharp

SUMMARY

Because of the ever-increasing applications made of two-phase gas-liquid flow, an investigation of this type of flow in various standard valves and fittings was considered advisable. An examination of the literature showed that data of this type were not available.

In the present study air was used as the gas phase and water as the liquid phase. An apparatus was constructed which would allow metered amounts of air and water to be passed through various standard valves and fittings. Air rates varied from about 0.01 to 0.10 pounds per second (7.43 to 74.3 SCFM). Water rates varied from 2 to 50 GPM. In the tests five different air rates were used at each constant water rate.

From the data obtained a series of curves were constructed for each valve showing air rate versus no-length pressure drop with the parameter of constant water rate. As a result of this study it was found that the correlation of Lockhart and Martinelli (1) could be used to predict pressure losses in systems containing valves if a multiplying factor is applied to the single-phase equivalent lengths of the valves. This multiplying factor was found to depend on the ratio of the liquid mass flow rate to that of the gas.

The data for the tee and elbows studied showed the same trend in regard to a single-phase equivalent length multiplying factor as did the

valves, but difficulties in obtaining sensitive pressure loss measurements precluded the formation of a general correlation that would include both the valve and fittings.

CHAPTER I

INTRODUCTION

This study was carried out for the purpose of obtaining information on two-phase pressure losses in valves and fittings. This investigation was part of a contract [Contract No. AF 33(616)-2660] let to the Engineering Experiment Station of the Georgia Institute of Technology by Wright Air Development Center, Dayton, Ohio. The overall objective of this contract is to establish parameters that govern the design of aircraft fuel systems where two-phase fuel flow exists. The first phase of this contract consisted of a literature survey (2) on two-phase (gas-liquid) fluid flow in pipes. This examination of the literature indicated that no data were available to allow the calculation of two-phase pressure losses in valves and fittings.

In addition to the literature survey (2) conducted for this project, another survey (3) was found which had been carried out for the Atomic Energy Commission at the University of Minnesota.

Investigations of the nature of two-phase flow have been carried on for many years, but only recently has much progress been made in this field. This advancement has been stimulated to a large degree by the many new industrial applications found using the medium of two phase flow. Applications in chemical reaction technology and in the transfer of heat or mass between phases are becoming increasingly common. Advances as a result of two-phase flow studies also will aid greatly in helping to increase the usefulness of older operations involving two-phase flow. Some of the more widely known of these operations involve evaporation, boiling, flashing, condensation, and the evolution of dissolved gases.

An examination of the literature has indicated that in practically all investigations to date, air or natural gas has been used as the gas phase, and water, benzene and hydrocarbon oils have been used as the liquid phase. Most of the information available (1, 4, 5, 6, 7, 8, 9, 10) is for co-current flow of the two phases in straight horizontal and vertical cylindrical ducts, ranging in size from capillary tubes to two inch pipes, without mass exchange between the phases. There are a few articles available which treat the applications involving mass exchange between the phases. Some of these articles may be found in references (11, 12, 13, 14).

In gas-liquid flow four possible combinations of viscous-turbulent flow conditions can occur, also a mobile boundary exists between the phases. Variation of this interfacial boundary results in changes in the flow channels of each phase and also changes in the channel roughness.

One of the most noticeable characteristics found in gas-liquid flow systems is the existence of various flow patterns. These flow patterns change smoothly from one type to another with no abrupt transition points. These flow patterns depend on the relative amounts and velocities of the phases; the nature of the phases, i.e. viscosity, density etc.; the geometry of the piping; entrance effects; and external vibrations and pulsations.

If increasing amounts of a gas phase are added to a horizontal pipe running full of liquid, the following successively occurring six distinct flow patterns are observed: 1) bubble flow in which bubbles of the gas move along the top of the pipe at approximately the same velocity as the liquid; 2) stratified flow in which the gas occupies the upper portion of the pipe with the liquid below, the two phases being joined by a smooth interface; 3) wave flow in which the interface is disturbed by waves; 4) plug flow in which large plugs of vapor and liquid move along the pipe with the liquid phase controlling; 5) slug flow in which rapidly moving slugs of liquid move along the pipe with the gas phase controlling; and 6) annular flow in which a high velocity gas stream flowing in a central core causes the liquid phase to assume an annular flow channel against the pipe wall.

As stated before, these flow patterns exhibit no abrupt transition points. This fact has led to some confusion among workers in this field who have given various names to the same flow patterns.

For this reason a flow pattern diagram is shown in fig. 1. This diagram is a plot of the mass flow rate of the air phase versus that of the water phase on which are shown the various flow pattern zones and their identifying names. Also a series of high-speed photographs of the flow patterns are shown in figs. 2 and 3 with their respective names and mass flow rates. These photographs were made using an electronic flash unit which produces a flash of approximately two microseconds duration.

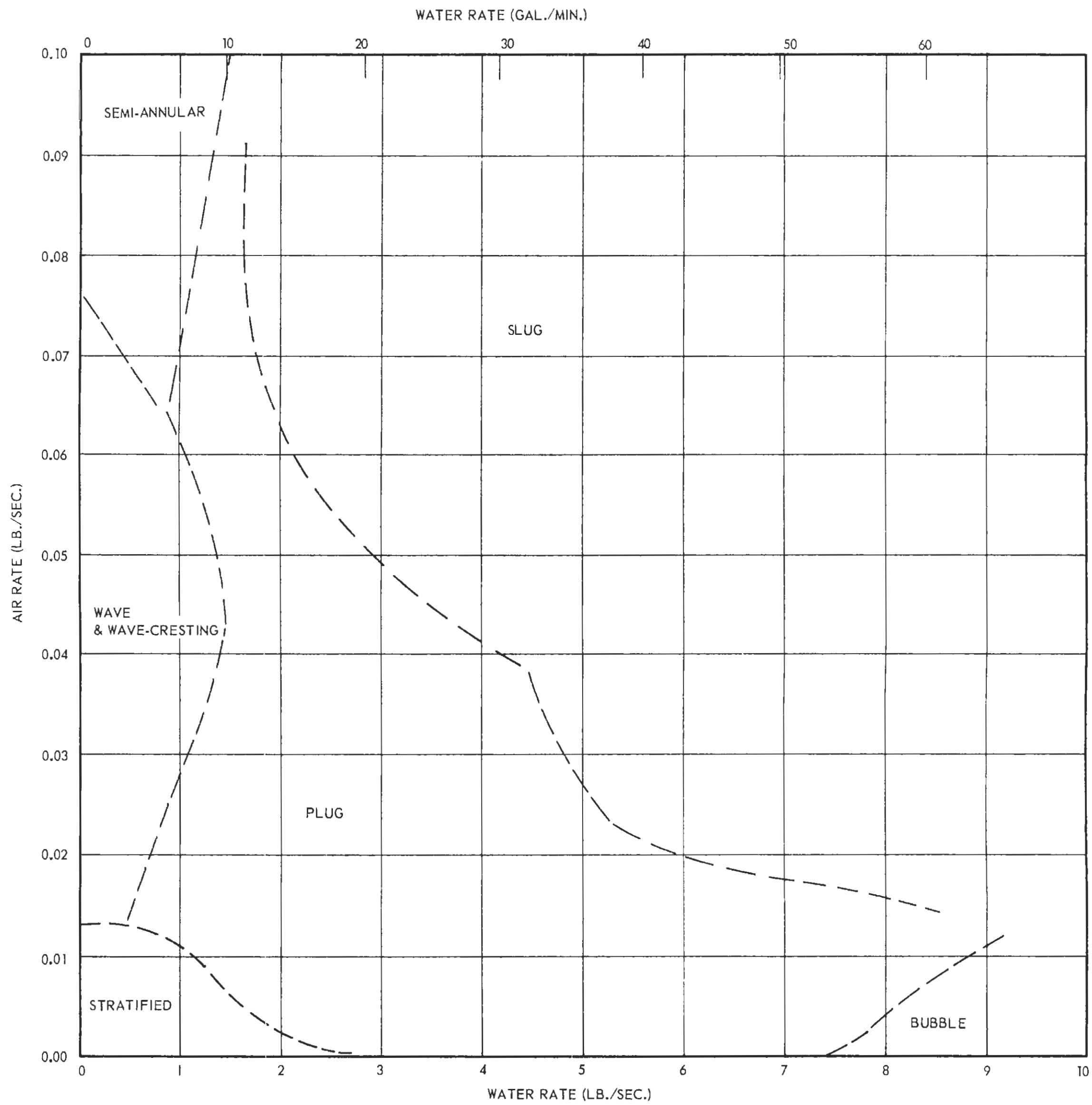
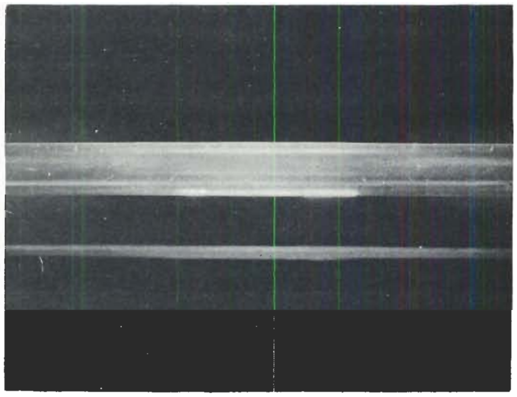
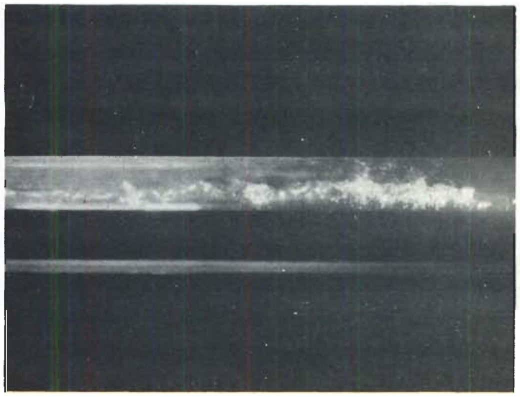


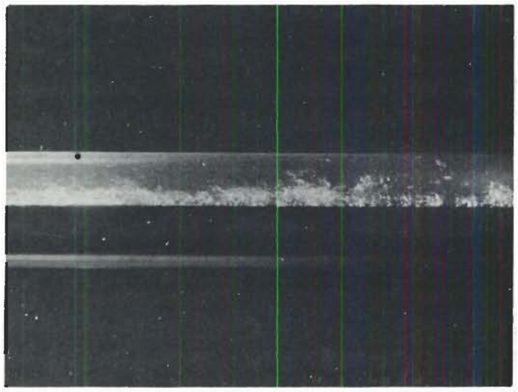
Figure 1. Observed Flow Patterns for Co-current Flow of Air-Water Mixtures in 1 1/2 Inch I.D. Horizontal Pipe.



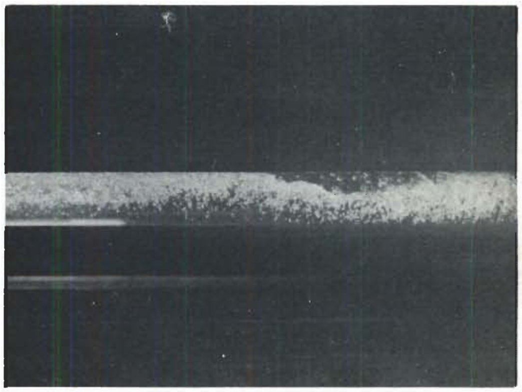
(a) STRATIFIED FLOW – WATER 2 GPM, AIR 0.0101 LB./SEC.



(b) WAVE FLOW – WATER 2 GPM, AIR 0.0620 LB./SEC.



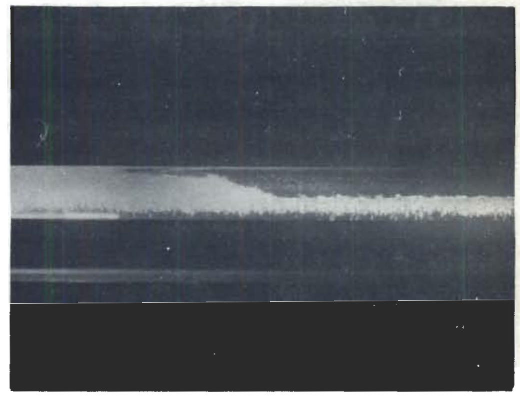
(c) SEMI-ANNULAR FLOW – WATER 2 GPM, AIR 0.0851 LB./SEC.



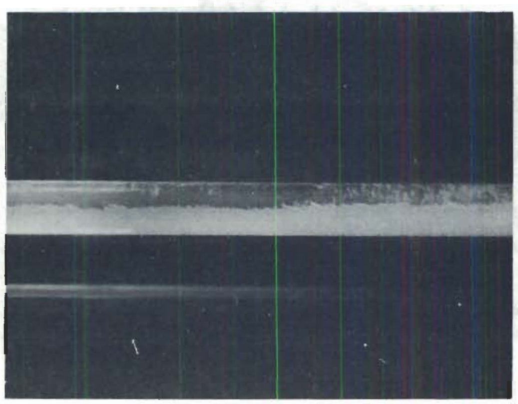
(d) PLUG FLOW – WATER 20 GPM, AIR 0.0150 LBS./SEC.

Figure 2. Flow Patterns - Flow from Left to Right.

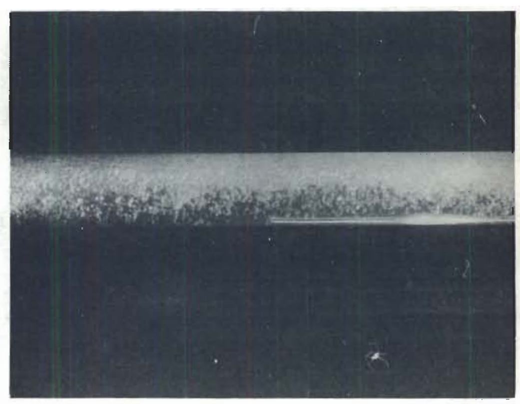
(a) SLUG-PLUG TRANSITION FLOW – WATER 30 GPM, AIR 0.0420 LB./SEC.



(b) PLUG-SLUG TRANSITION FLOW – WATER 40 GPM, AIR 0.0190 LB./SEC.



(c) SLUG FLOW – WATER 40 GPM, AIR 0.0620 LB./SEC.



(d) BUBBLE FLOW – WATER 60 GPM, AIR 0.0120 LB./SEC.

Figure 3. Flow Patterns - Flow from Left to Right.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

Schematic flow diagrams of sections of the experimental apparatus are shown in figs. 4 and 5. Photographs of portions of the equipment are shown in figs. 6 through 9.

The apparatus employed in this experiment consisted of the following components: separate devices for metering the air and water phases into the test system, which allow also for the determination of the phase temperatures and pressures; a mixing and calming pipe section; a test section consisting of the fitting under investigation and sufficient piping on either side of the fitting to serve as a calming zone; pressure measuring instruments which allow the measurement of the pressure drop across the test section and also the determination of an average pressure in the test section; and a means of separating the air and water phases to allow for water recycling once it has passed through the test section. The following paragraphs contain a more detailed discussion of the individual components.

The Air Supply System.--The air for this experiment was supplied by an Ingersoll-Rand 50 CFM compressor. The compressed air was then brought into an eight cubic foot storage tank at a pressure between ninety and one hundred twenty psig. Before entering and leaving the storage tank, the air was passed through glass wool filters to eliminate foreign matter. The air from the storage tank was regulated by two different size needle valves which served as a coarse and fine adjustment. From these valves the air passed through a 3/8 inch Klipfel diaphragm type throttle valve operated pneumatically. This throttling valve allowed the line pressure to be reduced from approximately one hundred psig to any desired value between zero and sixty psig. After throttling took place, the air passed into a Schutte and Koerting model 18200 Safeguard Rotometer fitted with an aluminum number 61-K rotor. The calibration curve furnished by the manufacturer was used with this instrument. The rotometer assembly was provided with a pressure gage calibrated in this laboratory and a thermometer. From the rotometer the air passed directly into the test system. The majority of the piping used in the air supply system was 3/8 inch standard iron pipe. The air entered into the test system from a piece of 3/8 inch pipe which was teed at ninety degrees into the 1 1/2 inch water supply line. The end of the 3/8 inch pipe, after brazing into the water pipe, was carefully rounded so that it would conform to the interior surface of the water line. Figure 7 shows the air supply control panel.

The Water Supply System.--The water supply system consisted of a conical bottom storage tank which held about one hundred twenty-five gallons; an Ingersoll-Rand 1 CORVNL pump having a capacity of 75 GPM against a head of one hundred twenty feet, two small rotometers mounted in parallel for measurement of flow rates below 14 GPM, and a rotometer bypass line equipped with a metering orifice calibrated in this laboratory for water flow rates of 20 through 60 GPM. The water storage tank was equipped with a thermometer. All pressure gages employed in this experiment were calibrated in these laboratories before use.

The Mixing and Calming Section.--The mixing and calming section consisted of fifteen feet of 1 1/2 inch copper pipe flanged to a five foot section of Pyrex Double Tough 1 1/2 inch glass pipe, two Crane Company number 1001 long sweep ninety degree drainage elbows, and several additional feet of 1 1/2 inch schedule eighty pipe which served to connect the calming section with the test section. The fifteen foot straight length of copper tubing was fitted with pressure taps at each end which were connected by 3/8 inch copper tubing to the pressure drop measuring components. The above mentioned copper tubing was used in the preliminary calibration of the apparatus.

The Test Sections.--There were two types of test sections employed in the pressure drop determinations. One type was used for the valves and the other type for the tee and elbows. A detailed drawing of the piping layouts in these sections can be found in fig. 5. Pyrex Double Tough glass pipe was used whenever practical for the observation of flow patterns. Several short joining sections in the valve test layout and also three ten foot lengths of pipe and some connecting pieces in the elbow test line were constructed from 1 1/2 inch schedule eighty iron pipe which matched exactly the 1 1/2 inch I.D. of the glass pipe. All flanges threaded onto the iron test section piping were fitted with brass bushings to fill up any thread space not taken up by the pipe. These bushings were milled to an inside diameter of 1 1/2 inches and cut to fit flush with the flange facing.

In the determination of single-phase pressure losses in valves and fittings it is accepted practice to place the up-stream pressure pick-up at least fifteen pipe diameters above the fitting tested and the down-stream pick-up about fifty diameters below the fittings. This is done to account for any pressure losses caused by the valve or fitting in the up or down-stream piping. There is, however, no criteria for placement of pressure pick-ups in two-phase valve and fitting determinations. In the valve test section the up-stream pick-up was about ninety-five diameters away and the down-stream pick-up about one hundred and ten diameters away. In the tee and elbow test section the up-stream pick-up was about fifty-five pipe diameters from the fittings and the down-stream pick-up about ninety diameters away. These distances should be sufficient to allow all valve and fitting pressure losses to be measured. Additional work would be needed to determine the minimum distances from the valve or fitting for placement of the pressure pick-up devices.

The Pressure Measuring Instruments.--The pressure drop across the test section was measured using two multiple pressure tap devices illustrated in fig. 8. The pressure impulses from these tap devices were transmitted through water-filled 3/16 inch copper tubing to a Republic pneumatic differential pressure transmitter. This device was calibrated in position before use against known water pressures. The output air signal from this instrument was read on a thirty inch mercury "U" manometer. A Bourdon type pressure gage calibrated in these laboratories was connected to the upstream pressure pick-up to allow calculation of an average pressure in the test section.

The Phase Separation Device.--A small cyclone separator shown in fig. 9 was used for separation of the air and water phases upon passage through the test section. The water leaving the cyclone dropped into the storage tank to be recycled.

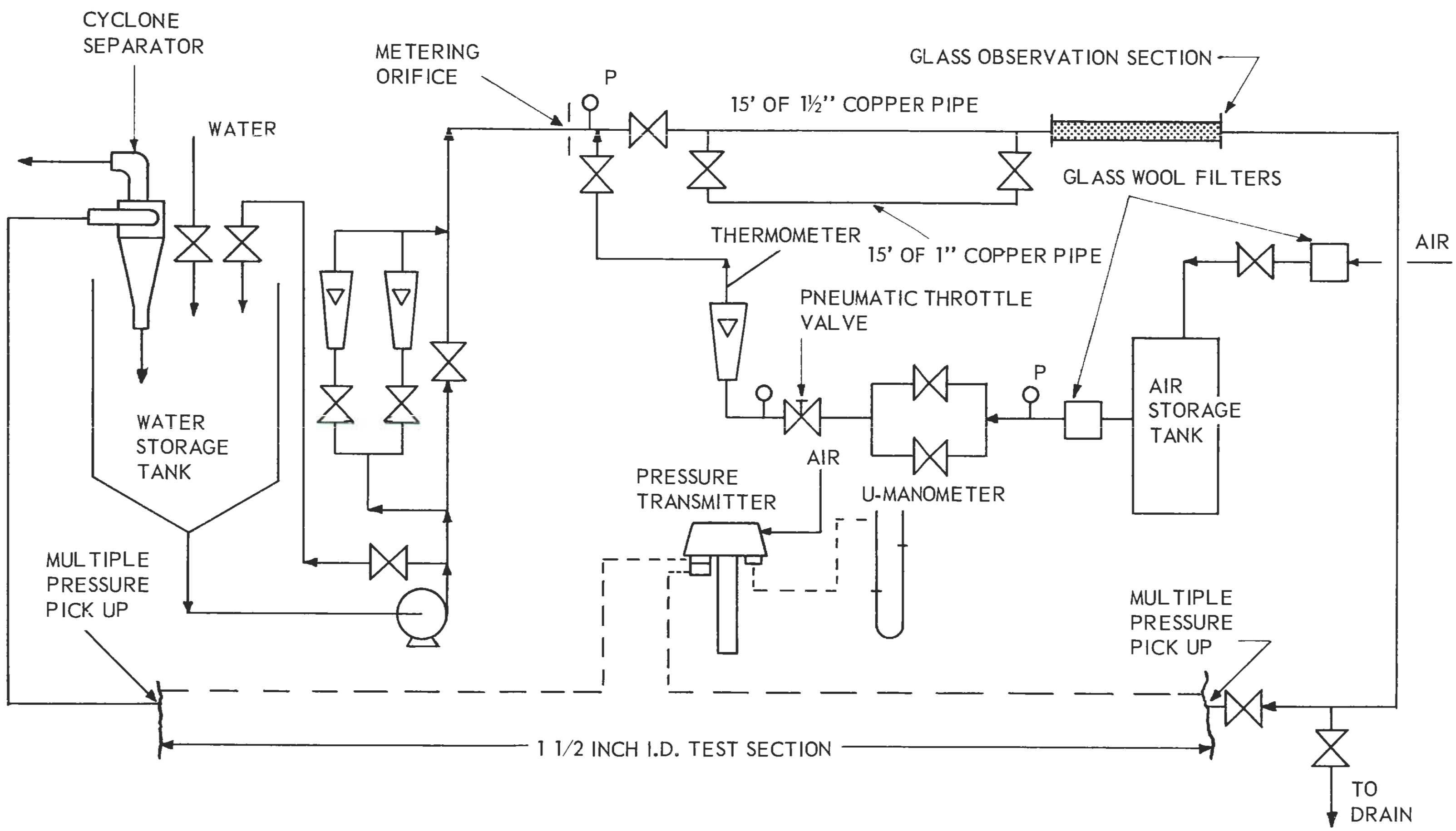


Figure 4. Schematic Diagram of Experimental Apparatus.

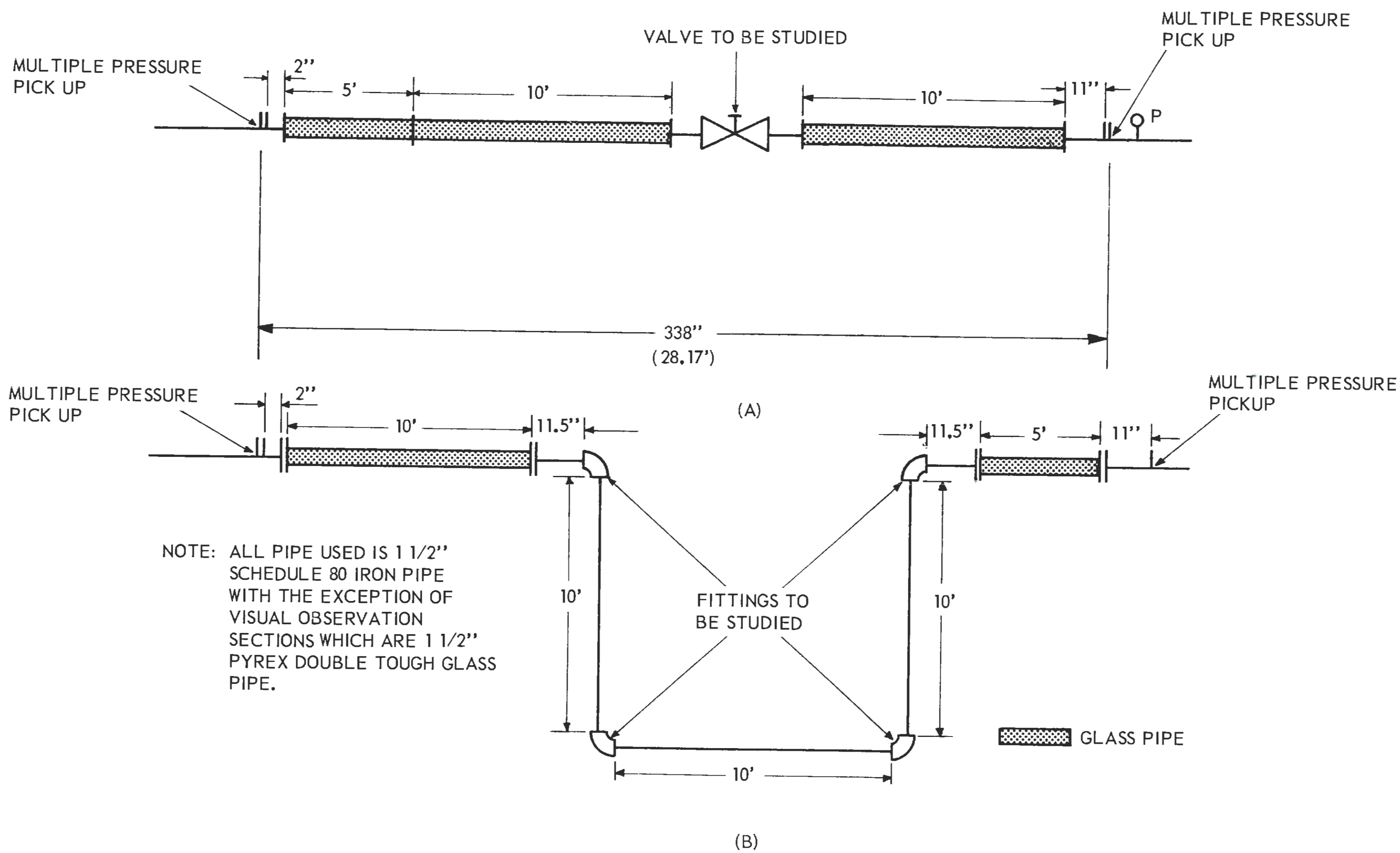


Figure 5. (A) Piping Diagram of Test Section for Valves.
(B) Piping Diagram of Test Section for Tees and Elbows.

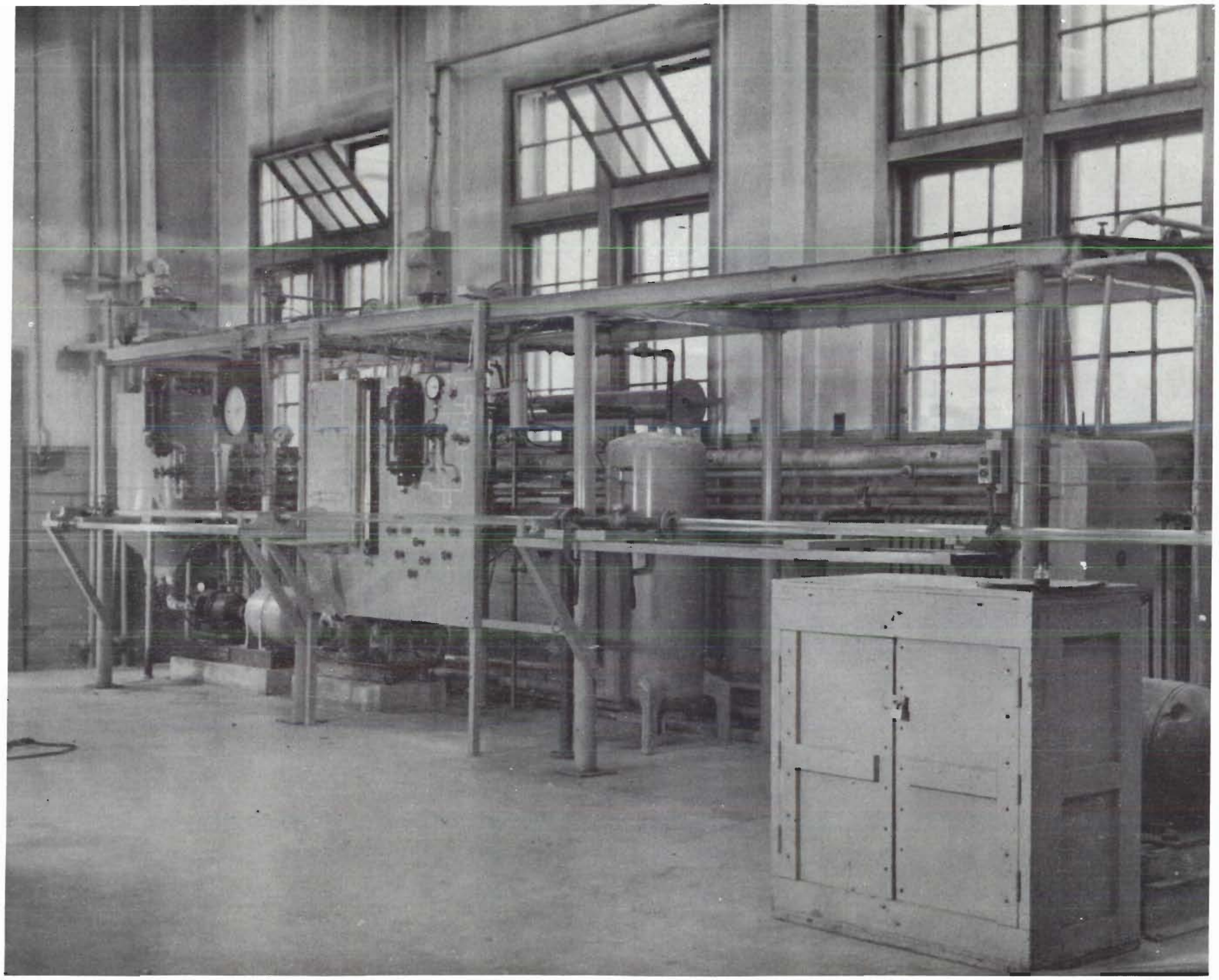


Figure 6. Experimental Apparatus.

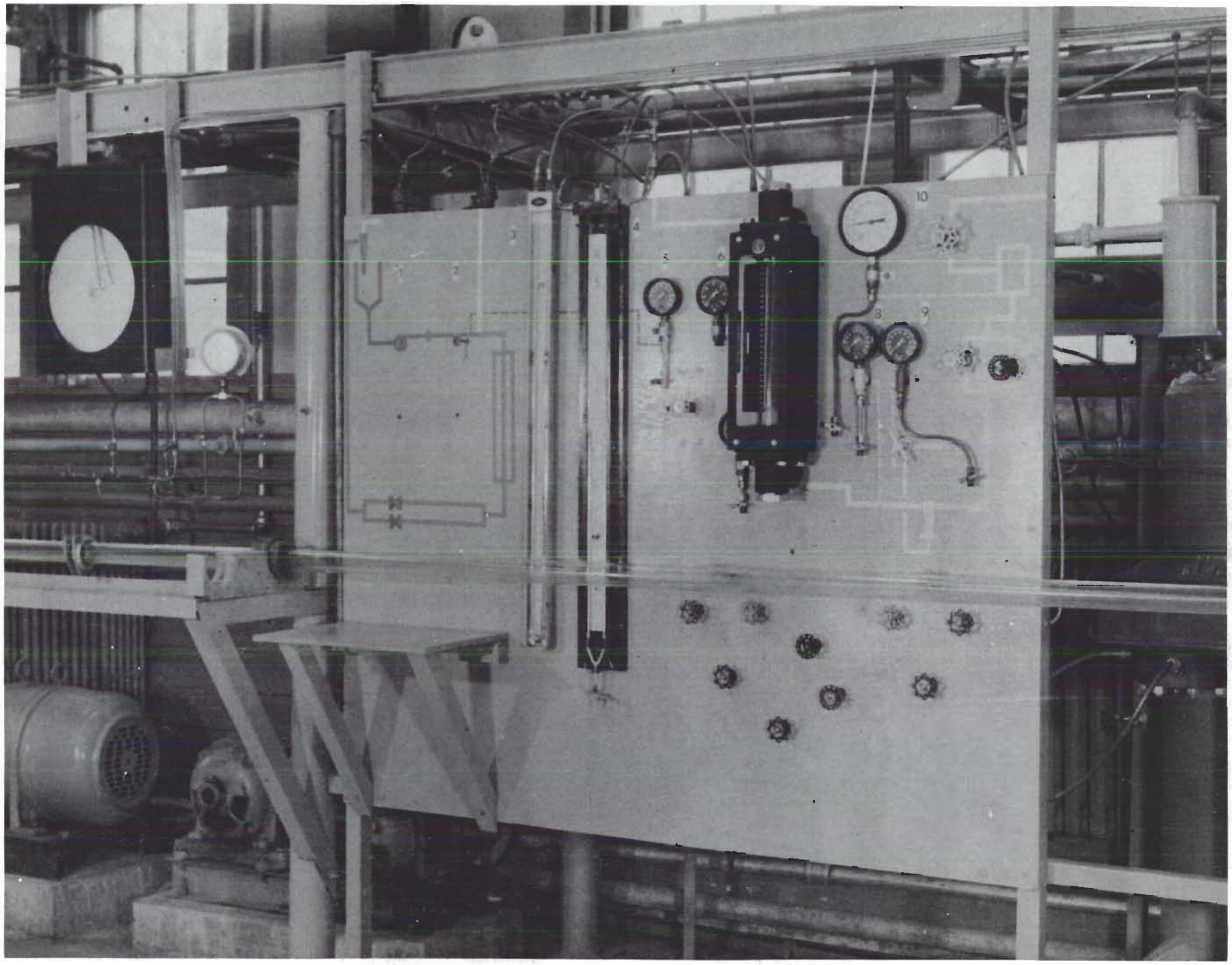


Figure 7. Control Panel.

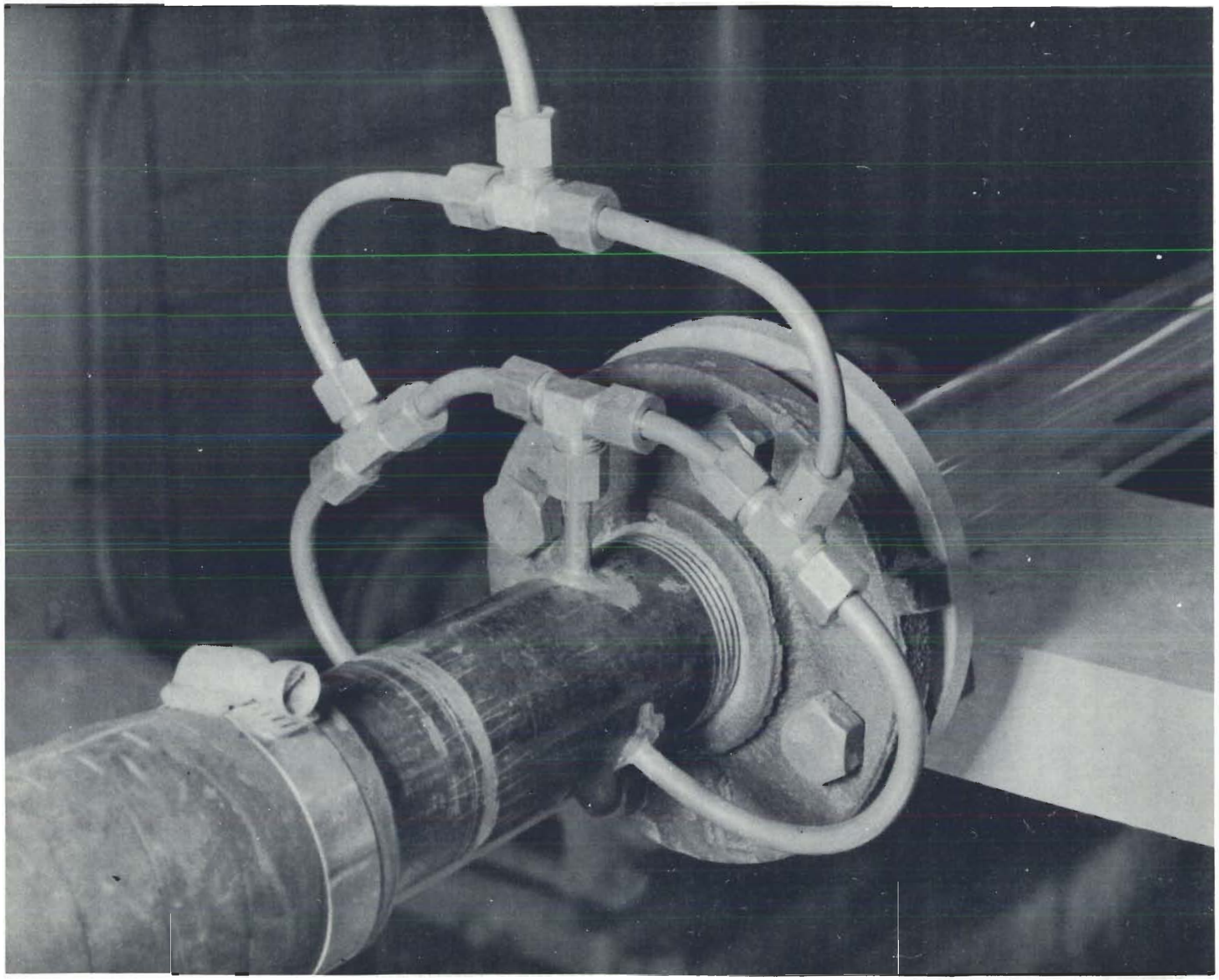


Figure 8. Pressure Pick-Up Device.

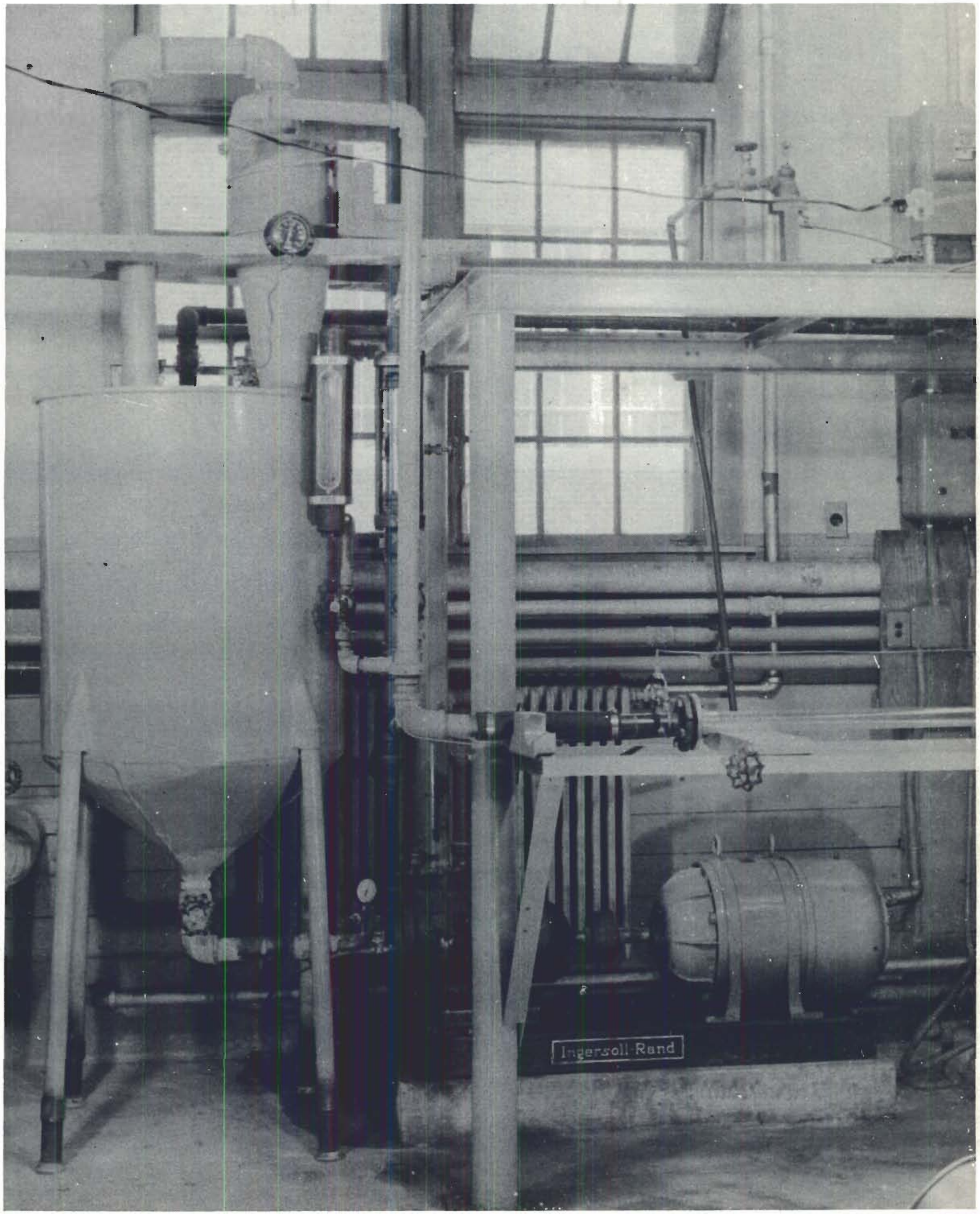


Figure 9. Water Storage Tank with Pump and Cyclone Separator.

CHAPTER III

EXPERIMENTAL PROCEDURE

The first phase of the experimental program consisted of the calibration of a fifteen foot straight section of 1 1/2 inch copper tubing used in the calming and mixing section. The first of these calibration runs consisted of a series of pressure drop measurements made at various constant water rates. These values were used to check the accuracy of the pressure drop measuring system by comparison of the experimental values with those predicted by the usual methods of calculation. A second series of calibration runs were made with co-current flow of air and water mixtures. These tests were made to check the accuracy of the air system instruments and to compare the results with those obtained by other investigations in this field. After checking the copper pipe section, a similar series of tests were made on the test section to be used for valves. In these tests the valve was removed and a piece of 1 1/2 inch schedule eighty pipe cut to match the length of the valve and its joining nipples were inserted in the test line. This kept the overall length of the test section a constant value and allowed pressure drop data to be gotten for a system of the same length as that employed when the valve to be tested was in place.

The calibration having been completed, the valve was inserted in the test line and a series of runs were made using five different air rates from approximately 0.01 to 0.10 pounds of air per second (7.43 to 74.3 SCFM) at various constant water rates ranging from 2 to 50 GPM.

A more exact identification of the valves and pipe fittings that were studied in this series of tests are presented in Appendix I.

The system was slightly modified for the study of the tee and elbows. Due to the relatively low pressure drop encountered in these fittings, four of each fitting were examined in series to furnish sufficient pressure drop for an accurate determination. Thus the system was modified by the addition of three ten-foot lengths of 1 1/2 inch schedule eighty pipe. The piping configuration for the tee and elbows is shown in fig. 5.

The majority of the test program was carried out in the summer months with water temperature ranging from approximately 18 to 26°C. Some of the later runs were made late in the fall and early winter and the resulting colder water was preheated before use. This was accomplished by the addition of open steam to the water storage tank.

CHAPTER IV

DISCUSSION OF RESULTS

The data and calculated results are presented in Tables 1 and 2 and figs. 10 through 21. The original data is on file in the School of Chemical Engineering of the Georgia Institute of Technology.

Flow of Water Only.--In an effort to determine the general accuracy of the pressure drop measuring components a series of runs were made using water only in each of two fifteen foot sections of copper pipe whose inside diameters were 1.60 and 1.06 inches. The values for the pressure drop gotten in this way agree within five per cent with those calculated using standard friction factor-Reynolds number plots. As a continuous check on the system, a series of water runs at each flow rate used in the two-phase tests were made on each valve and fitting examined. The pressure drops gotten in these runs also were within five per cent of the values predicted by standard methods and the use of equivalent length values for the valve or fitting under investigation. The temperature variations encountered in these runs were considerable, 17 to 35°C, but in all cases the actual water temperatures were used in the calculations and not an average value. In some of the later runs made early in the winter, the cold water was preheated with open steam to about 20°C.

Flow of Air and Water.--As a further check on the air system and the pressure drop measuring components, a series of air and water runs were made in the 1.60 inch I.D. copper pipe section. The data obtained in this manner were compared with the values predicted by the correlation of

Lockhart and Martinelli (1). Practically all of these experimentally determined pressure drops fall within plus or minus ten per cent of the value predicted by the correlation.

Upon completion of the copper pipe runs, the two-phase pressure drop was measured in the straight 338 inch valve test section 1.5 inches I.D. without a valve in the line. A sample of the data gotten from these runs together with the appropriate calculations can be found in Table I. A comparison of these values with those predicted by the Lockhart and Martinelli correlation can be seen in fig. 10. These experimental results also fall within plus or minus ten per cent of the predicted values with the majority of the experimental values falling slightly below the correlating curve.

Figure 11 shows a plot of air rate versus pressure drop with a parameter of constant water rate constructed from the straight test section data with no valve in the line. This plot became the standard for computing the no-length pressure drop curves shown for the various valves in figs. 12 through 21. The no-length plots were constructed by plotting the pressure drops versus air rate at constant water rates from the experimentally observed values with the valve to be tested in the line. The corresponding pressure drop values at the same air and water rates on the standard plot were then subtracted from those on the total pressure drop plots for each valve. This allowed the construction of a no-length pressure drop plot for each valve.

These no-length pressure drop plots all show a small nearly linear increase of pressure drop with increasing air rate at low water rates from about 2 to 14 GPM. These low water rate curves all have a very steep slope and are practically straight lines. As the liquid rate increases from about 20 to 50 GPM, small amounts of air cause very great increases in the pressure drop, but as the air rate increases the slopes of the pressure drop curves increase sharply showing less pressure loss increase with additional air. The higher the liquid rate the less the slope of the pressure drop curves at low air rates, thus showing the greatest relative increase in pressure loss to occur at high liquid rates and low air rates. The above trends seemed to be quite general in all the valves examined.

The values plotted in figs. 12 through 21 represent smoothed out values for these valves with the actual experimentally determined difference values for the pressure drops in some cases being ten to fifteen per cent higher or lower than those on the no-length plots. Due to the nature of the measurements made, a considerable amount of difficulty was encountered in reading the pressure drops. Fluctuations of the order of fifty to one hundred per cent were common in some of the smaller pressure drops encountered. The fluctuations in the pressure drops at low air and water rates had considerable amplitude but a relatively low frequency. As the air rate increased at low liquid rates the amplitude decreased but the frequency increased to a point at which the pressure drop measuring components could not respond rapidly enough, thus the measured pressure drop value became more steadied. At higher liquid rates and low air rates again the amplitude was quite high with the frequency somewhat higher than the low liquid rate pulsations. At the higher liquid and higher air rates the amplitude was lessened but the frequency greater. In this region violent slugging shook the apparatus. As the liquid rate was increased above 50 GPM air rates up to 0.05 pound of air per second produced little or no vibrations with a very steady pressure drop reading.

An effort was made to use the correlation of Lockhart and Martinelli (1) with the standard single-phase equivalent lengths for the valves studied to predict pressure losses. All the pressure drops calculated by this method gave values higher than those determined experimentally. All of the pressure drop values calculated for the valves were more in error as the air rates increased but the difference from the experimental value decreased as the liquid rates increased. This behavior was attributed to the valve since the air-water pressure drops measured without a valve in the line agreed within plus or minus ten per cent with those predicted by the Lockhart and Martinelli (1) relations. This pattern of deviation between the predicted and experimental pressure drop values pointed to the use of a multiplying factor which could be applied to the single-phase equivalent length for use with the Lockhart and Martinelli correlation (1). Such a multiplying factor was determined and found to depend upon the ratio of the mass flow rate of the liquid phase to the mass flow rate of the gas phase. This correction to the equivalent length allows the prediction of pressure drops that are within twenty-five per cent of the many experimental values examined. This agreement is felt to be quite good since the Lockhart and Martinelli method of calculating pressure loss is stated to be only $\pm$ 40 per cent accurate. The curve of the single-phase equivalent length multiplying factor versus the mass flow ratio can be found in fig. 22.

The following expression was used to calculate the single-phase equivalent length multiplying factor, designated Ψ, for the valve.

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP\text{-}MART}\left[\left(\frac{L}{D}\right)_{TS} D_{TS} + \Psi\left(\frac{L}{D}\right)_{V} D_{TS}\right] 2.035 = \Delta P_{TP\text{-}EXP}$$

With an actual valve, everything except the two pressure drop terms become constant, thus Ψ could be solved for explicitly for each run.

One can see from the above equation that if the L/D for the test section is large in comparison with the L/D for the fitting studied, very accurate experimental pressure drop measurements are needed to calculate Ψ since the result would be so strongly influenced by the L/D for the test section. A typical equation for a valve is that used to determine Ψ for the composition disc globe valve fully open. This valve was stated to have an L/D of 330(15) and the test section L/D was found to be 225. This relation is shown below.

$$\Psi = \frac{0.0119 \ \Delta P_{TP\text{-}EXP}}{\left(\frac{\Delta P}{\Delta L}\right)_{TP\text{-}MART}} - 0.682$$

In this equation each term is relatively small which allows a more accurate difference value to be gotten. This, however, is not true in the case of the tee and elbows since the L/D for the test section was several times larger than the L/D for the fittings. The equation for the standard 90° elbow is shown below. The L/D valve for the standard 90° elbow is 30.4 (16). Since four elbows were studied in series a total L/D of 121.6 was used. In these tests also some schedule 80 iron pipe was used along with the glass sections. To adjust the L/D valve for the iron pipe so that it could be used with the smooth glass pipe, the L/D valve for the iron pipe was multiplied by 1.1. This correction is the ratio of the arithmetic average of the iron pipe friction factor ($e/d = 0.0012$) to the arithmetic average friction factor as calculated from the Nekuradse equation over the range studied (14 to 50 GPM). This gave a value for the L/D of the pipe sections of 410. The equation for Ψ is shown below for the standard 90° elbow.

$$\Psi = \frac{3.233 \; \Delta P_{TP\text{-}EXP}}{\left(\frac{\Delta P}{\Delta L}\right)_{TP\text{-}MART}} - 3.372$$

In this expression the L/D from the straight pipe sections is almost four times that of the elbows. This fact coupled with difficulties in getting sensitive pressure drop readings and the $\pm$ 40 per cent accuracy of the Lockhart and Martinelli correlation (1) preclude the use of the elbows and tee in a more general single-phase equivalent length multiplying factor relation. However, a single-phase equivalent length multiplying factor was calculated for the tee and elbows. This factor showed the same tendency to approach unity as the mass flow ratio increased as did the valve; however, the factor values were somewhat above those for the valves at a corresponding mass flow ratio.

It was found that if no correction was applied to the tee and elbow equivalent lengths, the Lockhart and Martinelli correlation would lead to predicted values within about 20 per cent of the observed values.

Although all the data taken in this study were not used in the calculations, this data could be useful to others working in this field. For this reason Table 3, which presents the basic values recorded in all runs, is included in Appendix II.

CHAPTER V

CONCLUSIONS

The conclusions resulting from the present investigation may be summarized as follows:

1. The use of the Lockhart and Martinelli correlation (1) can be extended to various standard 1 1/2 inch valves by the use of a single-phase equivalent length multiplying factor based on the mass flow ratio of the two phases flowing.
2. The 1 1/2 inch tee and elbows studied exhibit the same general trend in regard to the single-phase equivalent length multiplying factor as the valves, but difficulties in obtaining sensitive pressure drop measurements precludes their use in forming a general single-phase equivalent length multiplying factor correlation for all 1 1/2 inch valves and fittings.

Table 1. Data and Results for Air-Water Calibration of 1 1/2 Inch Test Section 338 Inches Long Without Valve

Run No.	133	134	139	141	144	145	146	150
Q_L GPM	14	14	20	20	30	30	30	40
W_G lb./sec.	0.0501	0.0688	0.0301	0.0729	0.0329	0.0546	0.0778	0.0290
T_L °C	31	31	25	25	25	25	25	25
T_G °C	31	31	25	25	25	25	25	25
$P_{AVG.}$ psia.	16.7	17.7	17.6	20.0	20.7	22.5	25.4	23.2
$Re_L \times 10^{-4}$	3.75	3.75	4.70	4.70	7.05	7.05	7.05	9.40
f_L	0.0223	0.0223	0.0212	0.0212	0.0194	0.0194	0.0194	0.0183
$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	76.88	76.88	149.32	149.32	307.56	307.56	307.56	515.79
$Re_G \times 10^{-4}$	4.09	5.61	2.49	6.04	2.73	4.53	6.45	2.40
f_G	0.0219	0.0204	0.0245	0.0201	0.0240	0.0213	0.0198	0.0248
$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	38.16	65.53	14.66	59.52	14.59	32.84	54.76	10.44
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	2.01	1.21	10.18	2.51	21.08	9.37	5.62	49.43
ΔP_{TP-EXP} in.Hg.	5.96	7.09	4.92	9.60	8.25	11.16	13.36	10.11
$(\Delta P/\Delta L)_{TP-EXP}$ psi/ft.	0.104	0.124	0.086	0.168	0.144	0.195	0.233	0.176
$(\Delta P/\Delta L)_{TP-EXP}/(\Delta P/\Delta L)_L$	13.52	16.09	5.78	11.22	4.68	6.33	7.58	3.42

Table 1. Data and Results for Air-Water Calibration of 1 1/2 Inch Test Section 338 Inches Long Without Valve

Run No.	151	152	154	155	157
Q_L GPM	40	40	40	50	50
W_G lb./sec.	0.0538	0.0736	0.0946	0.0145	0.0500
T_L °C	25	25	25	25	25
T_G °C	25	25	25	25	25
$P_{AVG.}$ psia.	27.1	29.2	32.4	23.3	29.9
$Re_L \times 10^{-4}$	9.40	9.40	9.40	11.70	11.70
f_L	0.0183	0.0183	0.0183	0.0174	0.0174
$(\Delta P/\Delta L)_L \times 10^4$ psi./ft.	515.79	515.79	515.79	766.28	766.28
$Re_G \times 10^{-4}$	4.46	6.10	7.84	1.20	4.15
f_G	0.0214	0.0200	0.0190	0.0295	0.0218
$(\Delta P/\Delta L)_G \times 10^4$ psi./ft.	26.60	43.17	60.91	3.10	21.20
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	19.39	11.95	8.46	247.18	36.15
ΔP_{TP-EXP} in.Hg.	14.08	16.47	19.42	10.02	15.63
$(\Delta P/\Delta L)_{TP-EXP}$ psi./ft.	0.246	0.287	0.339	0.175	0.273
$(\Delta P/\Delta L)_{TP-EXP}/(\Delta P/\Delta L)_L$	4.76	5.57	6.57	2.28	3.56

Table 2A. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Composition Disc Globe Valve, Full Open

Run No.	241	242	243	244	245	247	248	249
Q_L (gal./min.)	14	14	14	14	14	20	20	20
W_G (lb./sec.)	0.0135	0.0226	0.0420	0.0735	0.0930	0.0140	0.0235	0.0490
T_L (°C)	27	27	27	27	27	27	28	28
T_G (°C)	33	33	33	32	32	31	31	31
$P_{AVG.}$ (psia.)	15.7	16.5	17.5	18.9	19.8	16.8	17.4	19.2
$Re_L \times 10^{-4}$	3.44	3.44	3.44	3.44	3.44	4.92	5.02	5.02
f_L	0.0227	0.0227	0.0227	0.0227	0.0227	0.0210	0.0209	0.0209
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	78.34	78.34	78.34	78.34	78.34	148.54	147.09	147.09
$Re_G \times 10^{-4}$	1.10	1.83	3.41	5.96	7.54	1.14	1.92	4.00
f_G	0.0300	0.0265	0.0227	0.0200	0.0191	0.0295	0.0261	0.0220
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	4.04	9.54	26.55	66.50	97.00	4.00	9.64	32.00
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	19.39	8.21	2.95	1.18	0.81	37.14	15.26	4.60
φ^2	5.20	7.08	11.00	16.6	19.8	4.09	5.75	9.07
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	40.7	55.5	86.2	130.0	155.0	60.8	84.6	133.0
$\Delta P_{exp.}$ (in.Hg)	4.2	5.1	9.6	9.4	12.0	5.7	7.5	10.2
W_L/W_G	145	86	47	25	20	200	116	57
Ψ	0.537	0.417	0.643	0.178	0.235	0.433	0.373	0.230

Table 2A. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe
338 Inches Long with Composition Disc Globe Valve, Full Open

Run No.	250	251	252	253	254	255	256	258
Q_L (gal./min.)	20	20	30	30	30	30	30	40
W_G (lb./sec.)	0.0815	0.1070	0.0160	0.0305	0.0450	0.0720	0.101	0.0150
T_L (°C)	28	28	29	29	29	29	29	30
T_G (°C)	31	31	32	32	32	32	32	32
$P_{AVG.}$ (psia.)	22.4	24.4	19.3	21.1	22.9	26.5	29.7	22.5
$Re_L \times 10^{-4}$	5.02	5.02	7.70	7.70	7.70	7.70	7.70	1.05
f_L	0.0209	0.0209	0.0190	0.0190	0.0190	0.0190	0.0190	0.0178
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	147.09	147.09	300.93	300.93	300.93	300.93	300.93	501.06
$Re_G \times 10^{-4}$	6.65	8.73	1.30	2.48	3.66	5.86	8.22	1.22
f_G	0.0196	0.0183	0.0288	0.0243	0.0215	0.0201	0.0188	0.0293
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	67.50	99.40	4.44	12.45	22.20	45.70	75.20	3.41
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	2.18	1.48	66.78	24.17	13.56	6.58	9.60	146.94
Φ^2	12.50	14.90	3.39	4.75	6.10	7.80	4.00	2.77
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	184.0	219.0	102.0	143.0	184.0	235.0	289.0	139.0
$\Delta P_{exp.}$ (in. Hg.)	13.7	17.5	10.0	12.5	15.6	19.3	22.5	14.6
W_L/W_G	27	25	255	138	92	57	40	370
Ψ	0.204	0.269	0.485	0.358	0.327	0.295	0.244	0.568

Table 2A. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Composition Disc Globe Valve, Full Open

Run No.	259	260	261	262	263	264	265	266
Q_L (gal./min.)	40	40	40	40	40	50	50	50
W_G (lb./sec.)	0.0300	0.0435	0.0680	0.0225	0.1073	0.0120	0.0245	0.0390
T_L (°C)	30	30	30	30	30	31	31	31
T_G (°C)	32	32	32	32	32	32	32	32
$P_{AVG.}$ (psia.)	24.9	27.1	31.0	23.7	35.7	25.2	27.7	30.6
$Re_L \times 10^{-4}$	1.05	1.05	1.05	1.05	1.05	1.34	1.34	1.34
f_L	0.0178	0.0178	0.0178	0.0178	0.0178	0.0169	0.0169	0.0169
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	501.06	501.06	501.06	501.06	501.06	743.19	743.19	743.19
$Re_G \times 10^{-4}$	2.44	3.54	5.54	1.83	8.73	0.98	1.99	3.18
f_G	0.0248	0.0226	0.0205	0.0265	0.0183	0.0312	0.0258	0.0231
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	10.42	18.35	35.55	6.58	68.60	2.07	6.50	13.35
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	48.09	27.31	14.09	76.15	7.30	359.03	114.34	55.67
Φ^2	3.71	4.55	6.00	3.26	7.45	2.23	2.92	3.60
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	186.0	228.0	301.0	163.0	373.0	166.0	217.0	268.0
$\Delta P_{exp.}$ (in. Hg.)	17.6	21.0	25.2	16.5	28.6	18.3	22.4	25.0
W_L/W_G	184	127	81	246	55	575	382	178
Ψ	0.444	0.414	0.314	0.522	0.230	0.626	0.546	0.428

Table 2A. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Composition Disc Globe Valve, Full Open

Run No.	267	268
Q_L (gal./min.)	50	50
W_G (lb./sec.)	0.0506	0.0610
T_L (°C)	31	31
T_G (°C)	32	32
$P_{AVG.}$ (psia.)	33.2	34.8
$Re_L \times 10^{-4}$	1.34	1.34
f_L	0.0169	0.0169
$(\Delta P/\Delta L)_L x10^4$ (psi./ft.)	743.19	743.19
$Re_G \times 10^{-4}$	4.12	4.97
f_G	0.0218	0.0210
$(\Delta P/\Delta L)_G x10^4$ (psi./ft.)	19.55	26.10
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	38.01	28.47
Φ^2	4.05	4.48
$(\Delta P/\Delta L)_{TP\text{-}MART} x10^3$ (psi./ft.)	301.0	333.0
$\Delta P_{exp.}$ (in.Hg.)	26.6	28.2
W_L/W_G	137	112
Ψ	0.369	0.326

Table 2B. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Composition Disc Globe Valve, 1/2 Total Turns Closed

Run No.	299	300	301	302	303	304	305	306
Q_L (gal./min.)	14	14	14	14	14	14	20	20
W_G (lb./sec.)	0.0135	0.0310	0.0540	0.0810	0.1100	0.0881	0.0145	0.0245
T_L (°C)	35	35	35	35	35	35	27	27
T_G (°C)	34	34	34	34	34	34	25	25
$P_{AVG.}$ (psia.)	15.6	17.2	18.7	19.9	23.3	21.3	17.0	18.6
$Re_L \times 10^{-4}$	4.06	4.06	4.06	4.06	4.06	4.06	4.92	4.92
f_L	0.0219	0.0219	0.0219	0.0219	0.0219	0.0219	0.0210	0.0210
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	75.39	75.39	75.39	75.39	75.39	75.39	148.54	148.54
$Re_G \times 10^{-4}$	1.09	2.51	4.37	6.55	8.90	7.13	1.20	2.03
f_G	0.0300	0.0245	0.0218	0.0159	0.0157	0.0159	0.0290	0.0258
$(\Delta P/ L)_G \times 10^4$ (psi./ft.)	4.06	15.90	39.50	60.70	94.80	68.20	4.16	9.67
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	18.70	4.75	1.91	1.24	0.80	1.11	35.70	15.40
φ^2	5.30	8.90	13.30	16.20	20.00	17.00	4.10	5.80
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	40.0	67.1	100.2	122.1	150.8	128.2	60.9	86.2
$\Delta P_{exp.}$ (in.Hg)	4.4	6.9	8.3	11.4	13.8	11.8	6.2	8.5
W_L/W_G	145	62	35	27	17	20	194	110
Ψ	0.472	0.417	0.228	0.326	0.313	0.319	0.408	0.373

Table 2B. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Composition Disc Globe Valve, 1/2 Total Turns Closed

Run No.	307	308	310	311	312	313	314	315
Q_L (gal./min.)	20	20	30	30	30	30	30	40
W_G (lb./sec.)	0.0460	0.0869	0.0163	0.0295	0.0513	0.0895	0.1050	0.0187
T_L (°C)	27	27	27	27	27	28	28	28
T_G (°C)	25	25	25	25	25	25	25	25
$P_{AVG.}$ (psia.)	19.4	23.4	19.9	21.7	24.1	27.8	30.1	22.5
$Re_L \times 10^{-4}$	4.92	4.92	7.38	7.38	7.38	7.53	7.53	10.00
f_L	0.0210	0.0210	0.0192	0.0192	0.0192	0.0191	0.0191	0.0180
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	148.54	148.54	304.24	304.24	304.24	302.56	302.56	506.93
$Re_G \times 10^{-4}$	3.80	7.11	1.35	2.44	4.24	7.40	8.70	1.55
f_G	0.0225	0.0159	0.0282	0.0250	0.0219	0.0158	0.0157	0.0275
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	28.60	58.70	4.37	11.60	27.80	53.00	67.00	4.96
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	5.19	2.53	69.60	26.20	10.94	5.71	4.52	102.20
Φ^2	8.60	11.70	3.35	4.60	6.90	8.25	9.10	3.00
$(\Delta P/\Delta L)_{TP\text{-}MART} \times 10^3$ (psi./ft.)	127.7	173.8	101.9	140.0	209.9	249.6	275.3	152.1
$\Delta P_{exp.}$ (in.Hg.)	11.5	15.8	11.6	14.5	18.8	23.8	26.0	17.2
W_L/W_G	62	32	250	142	80	45	37	300
Ψ	0.296	0.304	0.514	0.421	0.295	0.348	0.340	0.511

Table 2B. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Composition Disc Globe Valve, 1/2 Total Turns Closed

Run No.	316	317	318	319	320	321	322	323
Q_L (gal./min.)	40	40	40	40	50	50	50	50
W_G (lb./sec.)	0.0280	0.0540	0.0810	0.0960	0.0080	0.0177	0.0280	0.0400
T_L (°C)	28	28	28	28	29	29	29	29
T_G (°C)	25	25	25	25	25	25	25	25
$P_{AVG.}$ (psia.)	25.8	29.7	32.8	35.0	24.8	26.5	25.9	32.6
$Re_L \times 10^{-4}$	10.00	10.00	10.00	10.00	12.80	12.80	12.80	12.80
f_L	0.0180	0.0180	0.0180	0.0180	0.0170	0.0170	0.0170	0.0170
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	506.93	506.93	506.93	506.93	747.95	747.95	747.95	747.95
$Re_G \times 10^{-4}$	2.32	4.47	6.70	7.95	0.66	1.46	2.32	3.11
f_G	0.0250	0.0215	0.0159	0.0158	0.0159	0.0280	0.0247	0.0230
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	8.85	24.50	38.00	48.40	0.48	3.85	8.68	13.1
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	57.28	20.69	13.34	10.47	15.6802	194.27	86.16	57.10
Φ^2	3.50	5.10	6.10	7.00	1.67	2.57	3.16	3.55
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	177.4	258.5	309.2	354.9	124.9	192.2	236.4	265.5
$\Delta P_{exp.}$ (in.Hg.)	20.1	25.6	29.0	29.6	21.8	24.2	27.4	29.1
W_L/W_G	196	102	67	57	825	392	247	174
Ψ	0.513	0.447	0.334	0.234	1.08	0.629	0.537	0.477

Table 2C. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Bevel Seat Globe Valve, Full Open

Run No.	373	374	375	376	377	378	379	380
Q_L (gal./min.)	14	14	14	14	14	20	20	20
W_G (lb./sec.)	0.0135	0.0240	0.0415	0.0750	0.1090	0.0145	0.0255	0.0455
T_L (°C)	28	29	29	29	29	30	30	30
T_G (°C)	32	32	32	32	32	32	32	32
$P_{AVG.}$ (psia.)	15.9	16.8	18.0	19.8	20.8	17.6	21.6	19.5
$Re_L \times 10^{-4}$	3.51	3.59	3.59	3.59	3.59	5.24	5.24	5.24
f_L	0.0226	0.0225	0.0225	0.0225	0.0225	0.0207	0.0207	0.0207
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	77.97	77.61	77.61	77.61	77.61	145.61	145.61	145.61
$Re_G \times 10^{-4}$	1.10	1.95	3.34	6.10	8.88	1.18	2.08	3.70
f_G	0.0300	0.0260	0.0230	0.0198	0.0185	0.0297	0.0255	0.0223
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	4.00	10.40	22.00	65.00	123.00	4.10	9.00	28.00
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	19.40	7.46	3.53	1.19	0.63	35.51	16.18	5.20
Φ^2	5.20	7.40	10.10	16.50	22.40	4.15	5.65	8.60
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	40.4	56.4	78.4	128.0	174.0	60.4	82.3	125.0
$\Delta P_{exp.}$ (in.Hg.)	4.7	5.7	7.1	9.6	12.0	6.5	8.7	11.2
W_L/W_G	145	80	47	25	17	194	107	63
Ψ	0.666	0.489	0.364	0.197	0.126	0.562	0.534	0.361

Table 2C. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Bevel Seat Globe Valve, Full Open

Run No.	381	382	383	384	385	386	387	388
Q_L (gal./min.)	20	20	30	30	30	30	30	30
W_G (lb./sec.)	0.0805	0.0975	0.0165	0.0270	0.0475	0.0860	0.1020	0.0895
T_L (°C)	30	26	26	26	26	27	27	28
T_G (°C)	32	27	27	27	27	27	27	26
$P_{AVG.}$ (psia.)	23.2	24.7	19.8	21.4	23.8	27.4	29.7	28.1
$Re_L \times 10^{-4}$	5.24	4.81	7.21	7.21	7.21	7.38	7.38	7.53
f_L	0.0207	0.0211	0.0193	0.0193	0.0193	0.0192	0.0192	0.0191
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	145.61	148.57	305.88	305.88	305.88	304.24	304.24	302.56
$Re_G \times 10^{-4}$	6.55	7.20	1.36	2.22	3.91	7.08	8.40	7.39
f_G	0.0195	0.0192	0.0283	0.0250	0.0221	0.0193	0.0186	0.0192
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	64.00	86.00	4.50	10.00	24.00	60.00	75.00	63.00
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	2.28	1.73	67.97	30.59	12.75	5.07	4.06	4.80
Φ^2	12.35	13.90	3.38	4.38	6.35	8.70	9.55	8.90
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	180.0	207.0	103.0	134.0	194.0	265.0	291.0	269.0
$\Delta P_{exp.}$ (in.Hg.)	14.3	16.5	11.8	13.5	17.8	21.5	24.2	22.7
W_L/W_G	34	27	249	157	88	47	39	45
Ψ	0.244	0.247	0.635	0.485	0.385	0.264	0.288	0.300

Table 2C. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Bevel Seat Globe Valve, Full Open

Run No.	389	390	391	392	393	394	395	396
Q_L (gal./min.)	40	40	40	40	40	50	50	50
W_G (lb./sec.)	0.0165	0.0305	0.0500	0.0725	0.0770	0.0170	0.0335	0.0425
T_L (°C)	28	28	28	28	28	28	28	28
T_G (°C)	26	26	26	26	26	27	27	27
$P_{AVG.}$ (psia.)	23.0	25.8	28.8	32.5	36.5	21.9	31.6	32.2
$Re_L \times 10^{-4}$	10.00	10.00	10.00	10.00	10.00	12.60	12.60	12.60
f_L	0.0180	0.0180	0.0180	0.0180	0.0180	0.0171	0.0171	0.0171
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	506.93	506.93	506.93	506.93	506.93	752.47	752.47	752.47
$Re_G \times 10^{-4}$	1.36	2.52	4.13	5.98	8.01	1.40	2.76	3.50
f_G	0.0282	0.0243	0.0219	0.0201	0.0188	0.0281	0.0239	0.0226
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	3.90	10.00	22.40	38.0	56.0	3.40	9.80	15.00
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	129.98	50.69	22.63	13.34	9.05	221.31	76.78	50.16
Φ^2	2.83	3.67	4.90	6.20	6.80	2.50	3.25	3.70
$(\Delta P/\Delta L)_{TP\text{-}MART} \times 10^3$ (psi./ft.)	143.0	186.0	248.0	314.0	344.0	188.0	245.0	278.0
$\Delta P_{exp.}$ (in.Hg.)	17.3	20.2	24.0	27.2	27.2	23.8	27.0	28.4
W_L/W_G	341	180	110	75	56	407	207	164
Ψ	0.708	0.570	0.441	0.327	0.308	0.775	0.591	0.501

Table 2C. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Bevel Seat Globe Valve, Full Open

Run No.	397	398						
Q_L (gal./min.)	50	50						
W_G (lb./sec.)	0.0515	0.0580						
T_L (°C)	28	28						
T_G (°C)	27	27						
$P_{AVG.}$ (psia.)	35.0	36.5						
$Re_L \times 10^{-4}$	12.60	12.60						
f_L	0.0171	0.0171						
$(\Delta P/\Delta L)_L x10^4$ (psi./ft.)	752.47	752.47						
$Re_G \times 10^{-4}$	4.24	4.78						
f_G	0.0218	0.0210						
$(\Delta P/\Delta L)_G x10^4$ (psi./ft.)	19.00	22.00						
$(\Delta P/\Delta L)_L ; (\Delta P/\Delta L)_G$	39.60	34.20						
Φ^2	4.00	4.20						
$(\Delta P/\Delta L)_{TP-MART} x10^3$ (psi./ft.)	301.0	316.0						
$\Delta P_{exp.}$ (in.Hg.)	29.2	29.5						
W_L/W_G	135	119						
Ψ	0.442	0.403						

Table 2D. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Gate Valve, 3/4 Total Turns Closed

Run No.	1028	1029	1030	1031	1032	1033	1034	1035
Q_L (gal./min.)	14	14	14	14	14	14	20	20
W_G (lb./sec.)	0.0137	0.0244	0.0478	0.0696	0.0932	0.1100	0.0143	0.0263
T_L (°C)	24	24	24	24	24	24	24	24
T_G (°C)	26	26	26	26	26	26	26	26
$P_{AVG.}$ (psia.)	16.8	17.8	18.3	20.6	22.9	23.3	18.3	18.8
$Re_L \times 10^{-4}$	3.22	3.22	3.22	3.22	3.22	3.22	4.60	4.60
f_L	0.0231	0.0231	0.0231	0.0231	0.0231	0.0231	0.0213	0.0213
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	79.77	79.77	79.77	79.77	79.77	79.77	150.05	150.05
$Re_G \times 10^{-4}$	1.13	2.02	3.96	5.76	7.71	9.10	1.18	2.17
f_G	0.0303	0.0257	0.0220	0.0202	0.0190	0.0185	0.0295	0.0253
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	3.94	9.98	28.11	55.09	83.89	111.73	3.81	10.81
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	20.25	7.99	2.84	1.45	0.95	0.71	39.38	13.88
Φ^2	5.07	7.19	11.30	15.10	18.80	21.20	3.98	6.06
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	40.4	57.4	90.1	120.5	150.0	169.1	59.7	90.9
$\Delta P_{exp.}$ (in.Hg.)	5.7	7.7	9.6	12.5	15.7	18.1	9.6	11.8
W_L/W_G	145	79	42	26	20	15	195	103
Ψ	0.412	0.245	0.243	0.229	0.232	0.244	0.509	0.354

Table 2D. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Gate Valve, 3/4 Total Turns Closed

Run No.	1036	1037	1038	1039	1040	1041	1042	1043
Q_L (gal./min.)	20	20	20	30	30	30	30	40
W_G (lb./sec.)	0.0518	0.0747	0.0955	0.0180	0.0305	0.0612	0.0844	0.0190
T_L (°C)	24	24	24	25	25	25	25	26
T_G (°C)	26	26	26	26	26	26	26	26
$P_{AVG.}$ (psia.)	22.0	24.9	26.0	21.2	24.7	28.2	33.6	27.8
$Re_L \times 10^{-4}$	4.60	4.60	4.60	7.05	7.05	7.05	7.05	9.62
f_L	0.0213	0.0213	0.0213	0.0194	0.0194	0.0194	0.0194	0.0182
$(\Delta P/\Delta L)_L x10^4$ (psi./ft.)	150.05	150.05	150.05	307.56	307.56	307.56	307.56	512.81
$Re_G \times 10^{-4}$	4.29	6.17	7.89	1.49	2.52	5.06	6.97	1.57
f_G	0.0213	0.0200	0.0189	0.0278	0.0245	0.0208	0.0194	0.0274
$(\Delta P/\Delta L)_G x10^4$ (psi./ft.)	30.24	52.12	77.04	4.94	10.74	32.12	47.80	27.81
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	4.96	2.88	1.95	62.26	28.64	9.58	6.43	124.16
Φ^2	8.80	11.20	13.30	3.46	4.48	6.65	7.87	2.88
$(\Delta P/\Delta L)_{TP\text{-}MART} x10^3$ (psi./ft.)	132.0	168.1	199.6	106.4	137.8	204.5	242.0	147.7
$\Delta P_{exp.}$ (in.Hg.)	15.3	19.7	23.3	18.3	20.6	26.6	29.0	28.2
W_L/W_G	55	37	29	232	137	68	47	295
Ψ	0.287	0.293	0.291	0.562	0.454	0.358	0.308	0.656

Table 2D. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Gate Valve, 3/4 Total Turns Closed

Run No.	1044	1045						
Q_L (gal./min.)	40	40						
W_G (lb./sec.)	0.0079	0.0056						
T_L (°C)	26	26						
T_G (°C)	26	26						
$P_{AVG.}$ (psia.)	25.1	23.1						
$Re_L \times 10^{-4}$	9.62	9.62						
f_L	0.0182	0.0182						
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	512.81	512.81						
$Re_G \times 10^{-4}$	0.65	0.46						
f_G	0.0347	0.0383						
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	25.13	23.06						
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	512.86	854.76						
Φ^2	2.07	1.88						
$(\Delta P/\Delta L)_{TP\text{-}MART} \times 10^3$ (psi./ft.)	106.2	96.4						
$\Delta P_{exp.}$ (in.Hg.)	26.8	23.2						
W_L/W_G	700	988						
Ψ	0.959	0.901						

Table 2E. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Y Pattern Swing Check Valve

Run No.	641	642	643	644	645	647	648	649
Q_L (gal./min.)	14	14	14	14	14	14	20	20
W_G (lb./sec.)	0.0135	0.0240	0.0420	0.0695	0.0930	0.1010	0.0140	0.0260
T_L (°C)	24	24	24	24	24	24	25	25
T_G (°C)	21	21	21	21	21	21	22	22
$P_{AVG.}$ (psia.)	15.0	16.3	16.9	18.3	19.9	20.2	16.7	17.3
$Re_L \times 10^{-4}$	3.22	3.22	3.22	3.22	3.22	3.22	4.70	4.70
f_L	0.0231	0.0231	0.0231	0.0231	0.0231	0.0231	0.0212	0.0212
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	79.77	79.77	79.77	79.77	79.77	79.77	149.32	149.32
$Re_G \times 10^{-4}$	1.13	2.01	3.52	5.82	7.79	8.46	1.17	2.17
f_G	0.0300	0.0258	0.0226	0.0202	0.0190	0.0187	0.0297	0.0253
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	4.23	10.60	27.41	61.92	96.20	109.73	4.06	11.48
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	19.20	7.66	2.96	1.31	0.84	0.79	37.32	13.20
Φ^2	5.20	7.33	10.90	15.80	19.45	19.95	4.10	6.23
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	42.2	59.0	87.7	127.2	156.6	170.0	62.1	94.4
$\Delta P_{exp.}$ (in.Hg.)	2.8	3.7	5.3	7.7	9.6	10.2	4.3	5.7
W_L/W_G	145	80	47	26	20	18	200	105
Ψ	0.469	0.281	0.163	0.168	0.235	0.141	0.618	0.270

Table 2E. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Y Pattern Swing Check Valve

Run No.	650	651	652	654	655	660	662	663
Q_L (gal./min.)	20	20	20	30	30	30	30	40
W_G (lb./sec.)	0.0450	0.0740	0.0970	0.0130	0.0280	0.0795	0.1020	0.0175
T_L (°C)	25	25	25	26	26	26	26	21
T_G (°C)	22	22	22	22	22	22	22	22
$P_{AVG.}$ (psia.)	19.3	22.2	23.6	19.0	19.9	25.3	28.2	21.3
$Re_L \times 10^{-4}$	4.70	4.70	4.70	7.21	7.21	7.21	7.21	8.58
f_L	0.0212	0.0212	0.0212	0.0193	0.0193	0.0193	0.0193	0.0186
$(\Delta P/\Delta L)_L \times 10^4$ (psi./ft.)	149.32	149.32	149.32	305.88	305.88	305.88	305.88	524.67
$Re_G \times 10^{-4}$	3.76	6.19	8.11	1.09	2.34	6.65	8.53	1.46
f_G	0.0223	0.0199	0.0188	0.0302	0.0249	0.0196	0.0187	0.0279
$(\Delta P/\Delta L)_G \times 10^4$ (psi./ft.)	27.24	57.17	86.90	3.13	11.43	56.90	80.20	4.67
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	5.56	2.65	1.74	99.84	27.34	5.49	3.90	111.73
Φ^2	8.38	11.50	13.80	3.03	4.57	8.40	9.75	2.95
$(\Delta P/\Delta L)_{TP-MART} \times 10^3$ (psi./ft.)	127.0	174.2	209.1	94.7	142.8	262.5	304.7	153.9
$\Delta P_{exp.}$ (in.Hg.)	7.9	10.4	12.5	6.5	9.6	16.0	18.4	10.8
W_L/W_G	65	37	29	305	150	50	40	322
Ψ	0.255	0.125	0.130	0.587	0.515	0.190	0.161	0.667

Table 2E. Data and Results for Co-Current Flow of Air and Water in 1 1/2 Inch Pipe 338 Inches Long with Y Pattern Swing Check Valve

Run No.	664	665	668	669	670	671	672	673
Q_L (gal./min.)	40	40	50	50	50	50	50	50
W_G (lb./sec.)	0.0310	0.0540	0.0080	0.0190	0.0340	0.0480	0.0695	0.0760
T_L (°C)	21	21	22	22	22	22	22	22
T_G (°C)	22	22	22	22	22	22	22	22
$P_{AVG.}$ (psia.)	23.0	27.0	22.5	24.3	27.4	29.6	32.0	33.8
$Re_L \times 10^{-4}$	8.58	8.58	11.00	11.00	11.00	11.00	11.00	11.00
f_L	0.0186	0.0186	0.0176	0.0176	0.0176	0.0176	0.0176	0.0176
$(\Delta P/\Delta L)_L x10^4$ (psi./ft.)	524.67	524.67	775.59	775.59	775.59	775.59	775.59	775.59
$Re_G \times 10^{-4}$	2.59	4.51	0.67	1.59	2.84	4.01	5.81	6.35
f_G	0.0243	0.0214	0.0343	0.0273	0.0338	0.0219	0.0202	0.0198
$(\Delta P/\Delta L)_G x10^4$ (psi./ft.)	11.78	26.87	1.32	4.72	11.65	19.84	35.41	39.29
$(\Delta P/\Delta L)_L/(\Delta P/\Delta L)_G$	44.29	19.42	587.57	164.32	66.57	39.09	21.90	19.74
Φ^2	3.85	5.20	2.02	2.68	3.40	4.00	4.95	5.10
$(\Delta P/\Delta L)_{TP\text{-}MART} x10^3$ (psi./ft.)	200.9	271.3	156.7	207.9	263.7	310.2	383.9	395.6
$\Delta P_{exp.}$ (in.Hg.)	12.9	17.2	11.7	14.1	17.4	19.8	23.2	24.0
W_L/W_G	177	102	825	365	205	145	97	90
Ψ	0.358	0.317	0.899	0.545	0.450	0.339	0.163	0.176

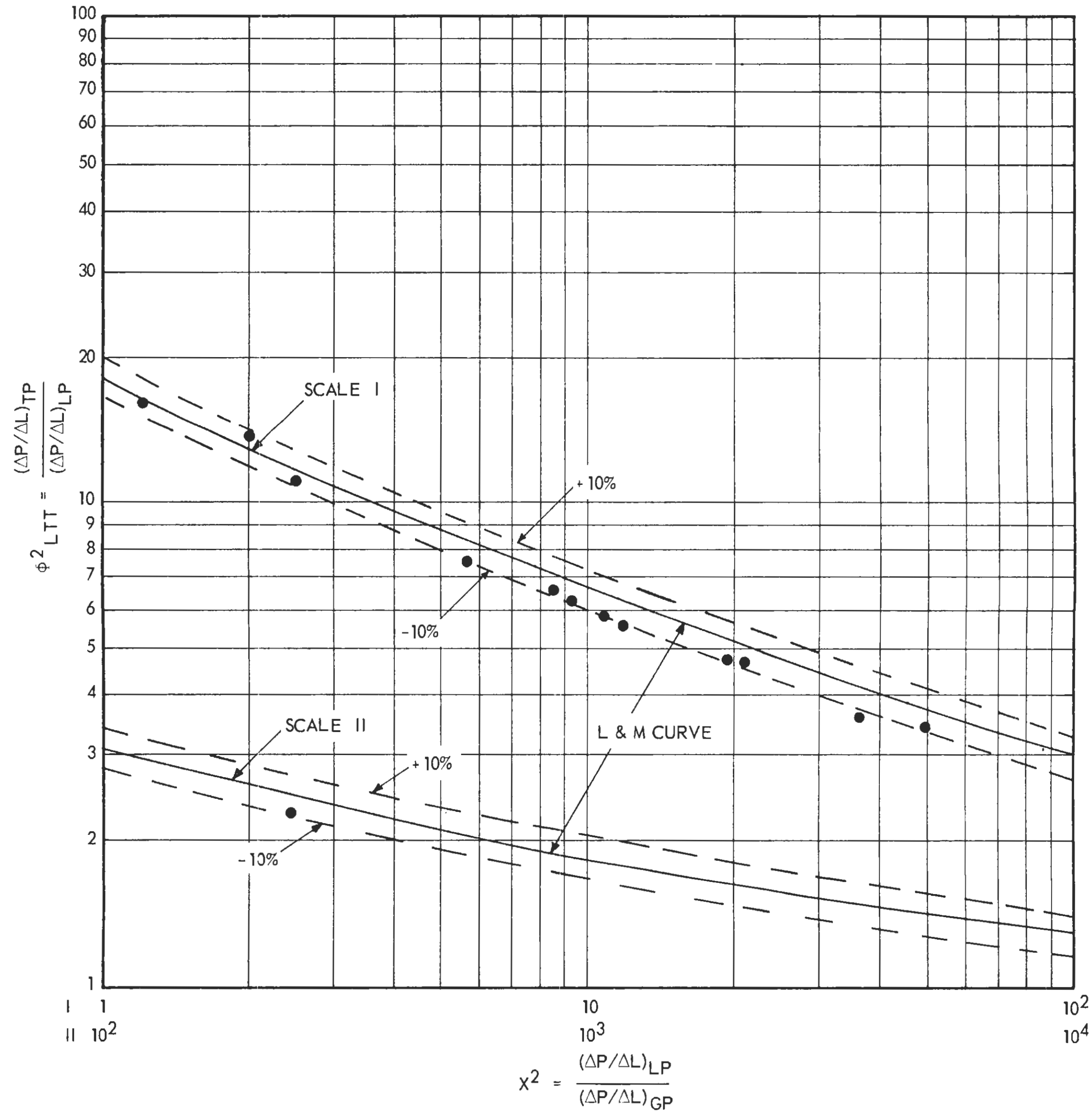


Figure 10. Comparison of Calibration Data on 338 Inch Straight Horizontal Test Section of 1 1/2 Inch I.D. Pipe for Co-current Turbulent-Turbulent Flow of Air and Water with Correlation of Lockhart and Martinelli (1).

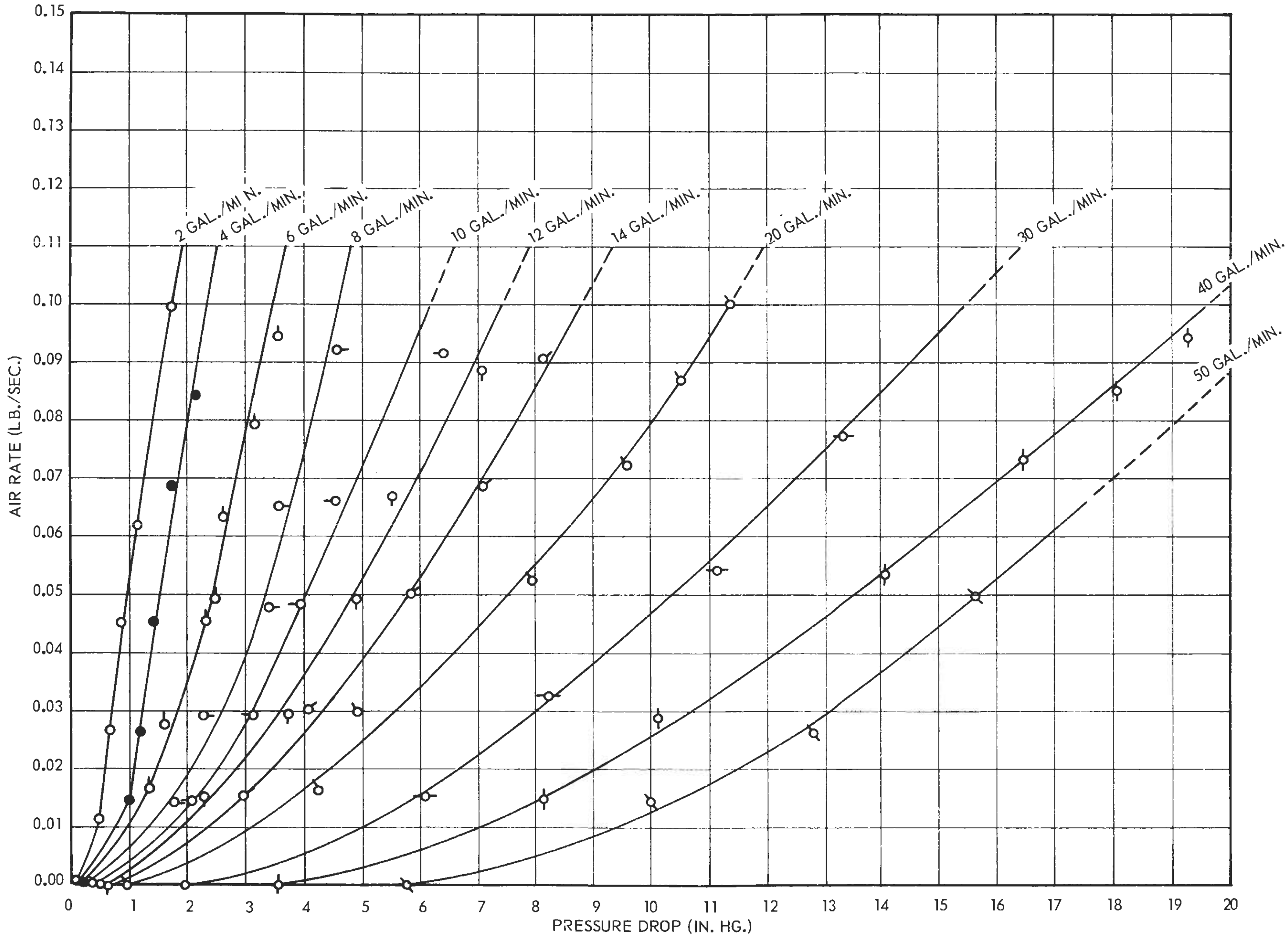


Figure 11. Air Rate Vs. Pressure Drop at Constant Water Rates for 338 Inch Straight Horizontal 1 1/2 Test Section with No Valves.

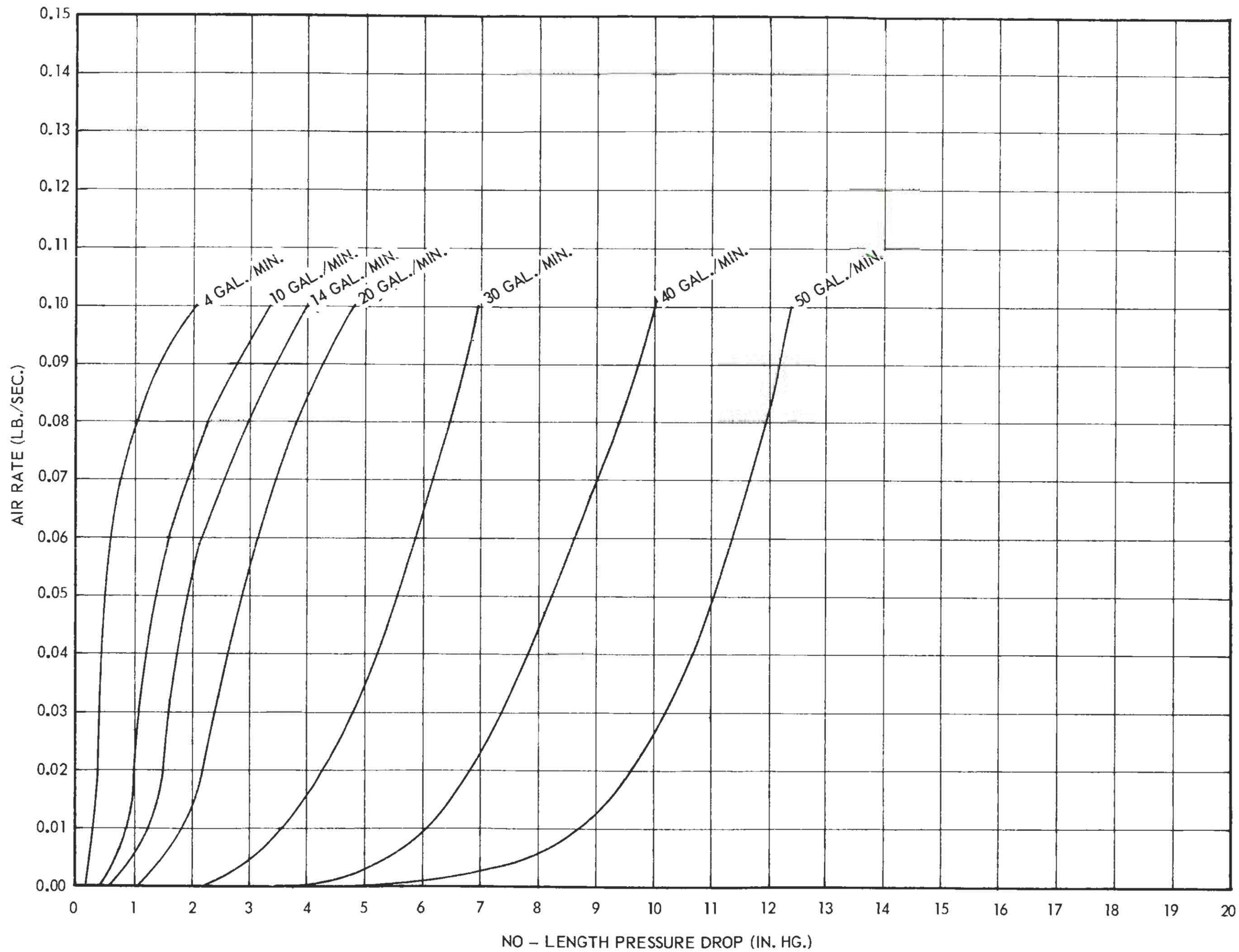


Figure 12. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Composition Disc Globe Valve - Full Open.

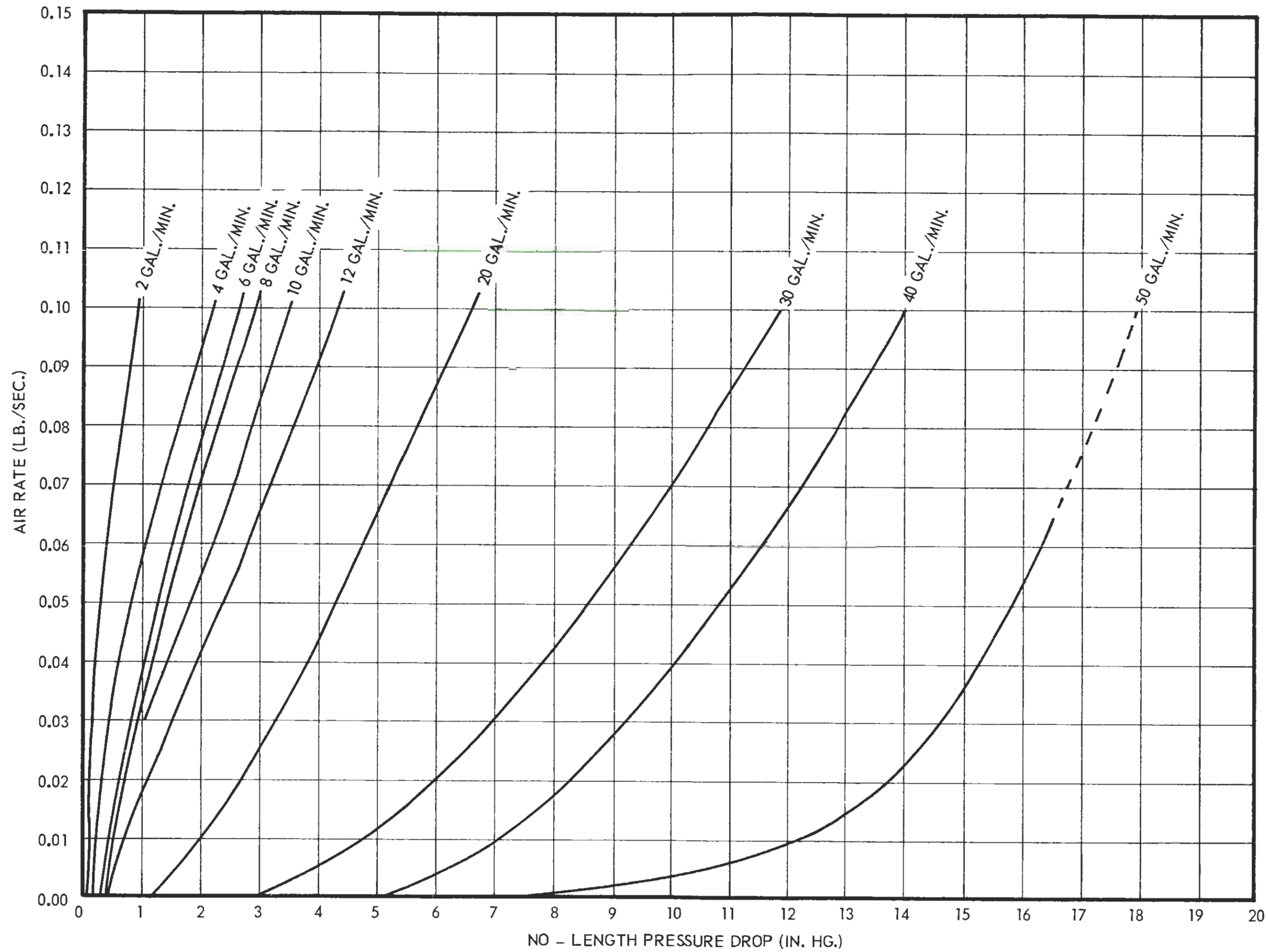


Figure 13. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Composition Disc Globe Valve - One-half Total Turns Closed.

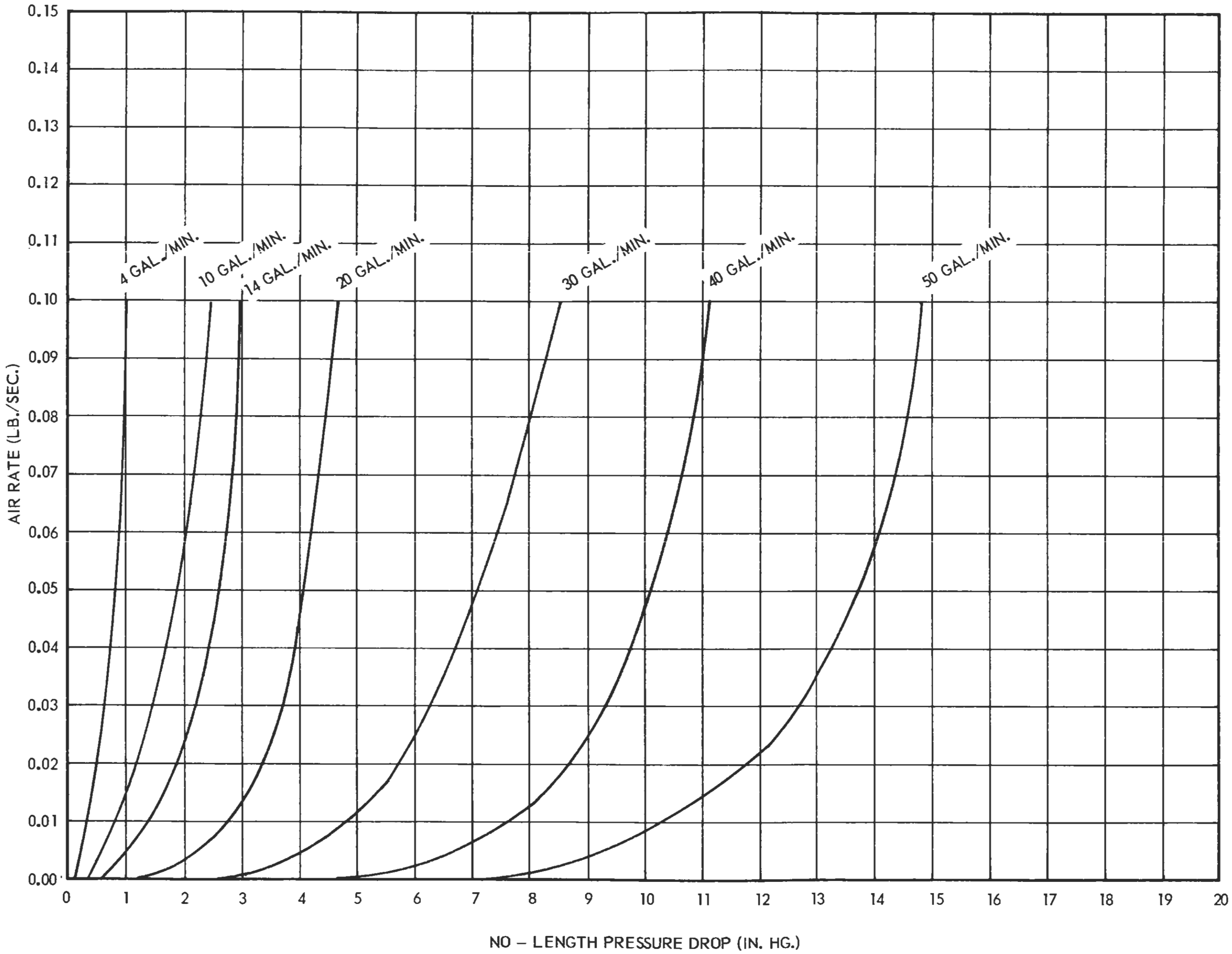


Figure 14. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Bevel Seat Globe Valve - Full Open.

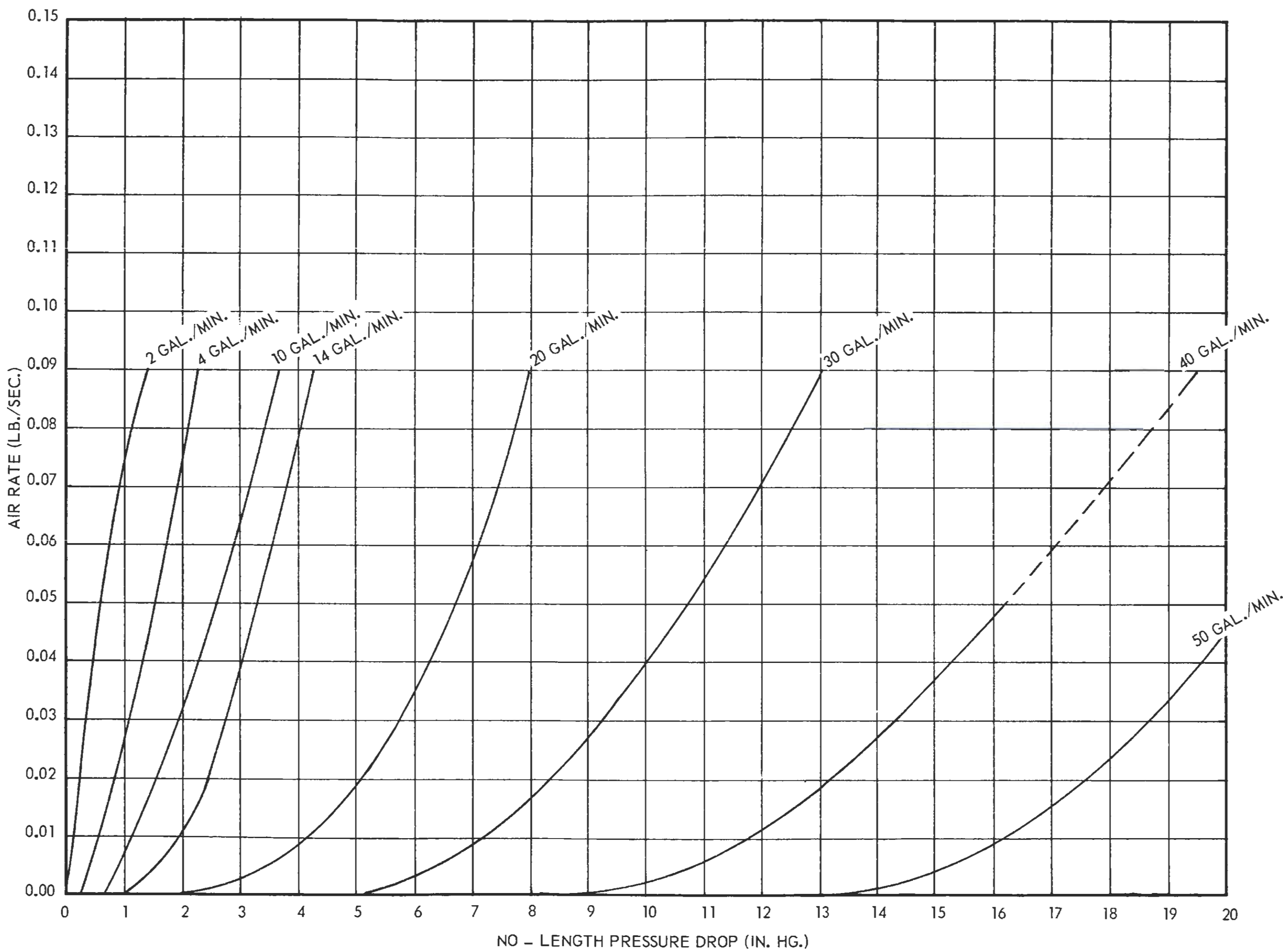


Figure 15. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Bevel Seat Globe Valve - One-half Total Turns Closed.

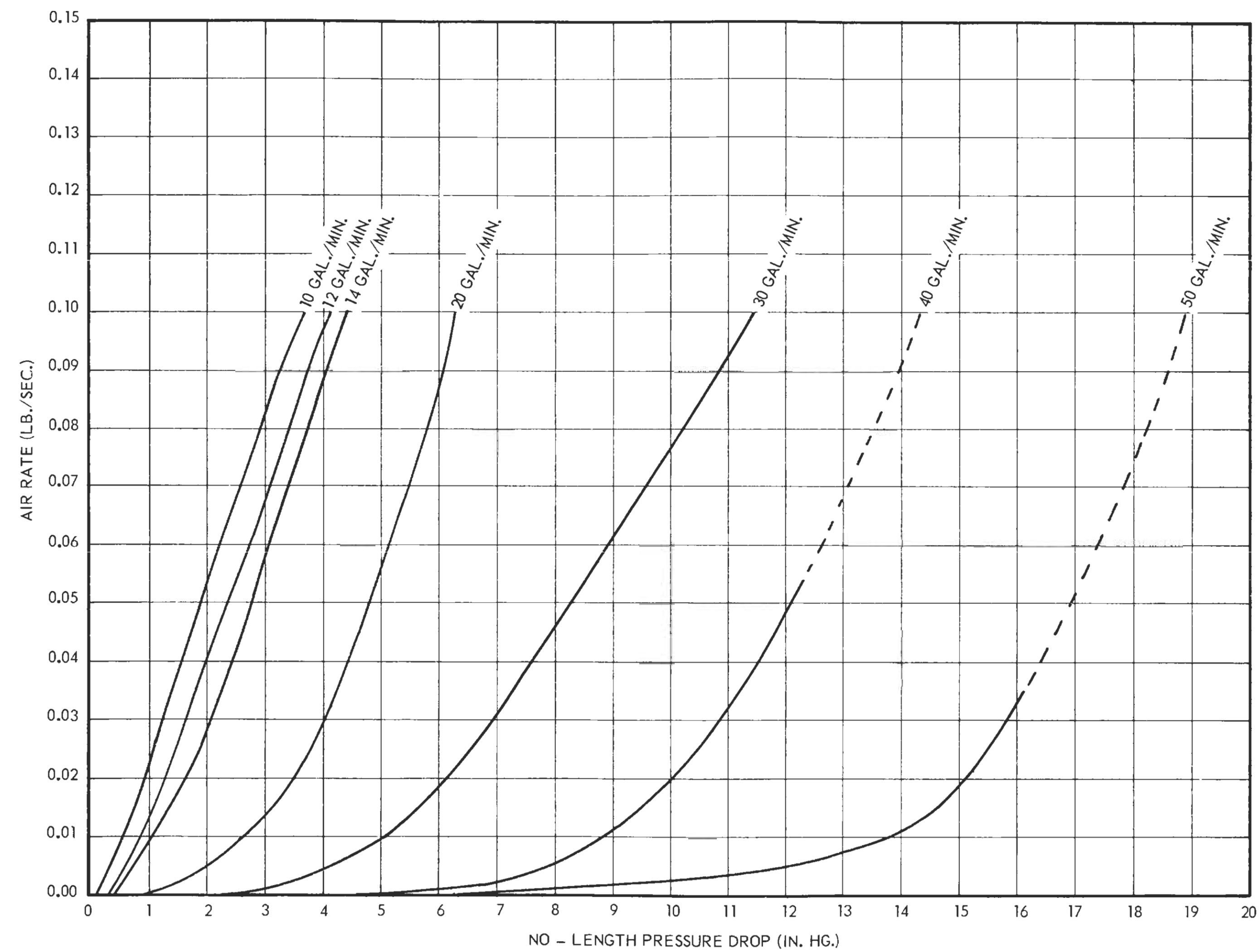


Figure 16. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Plug Disc Globe Valve - Full Open.

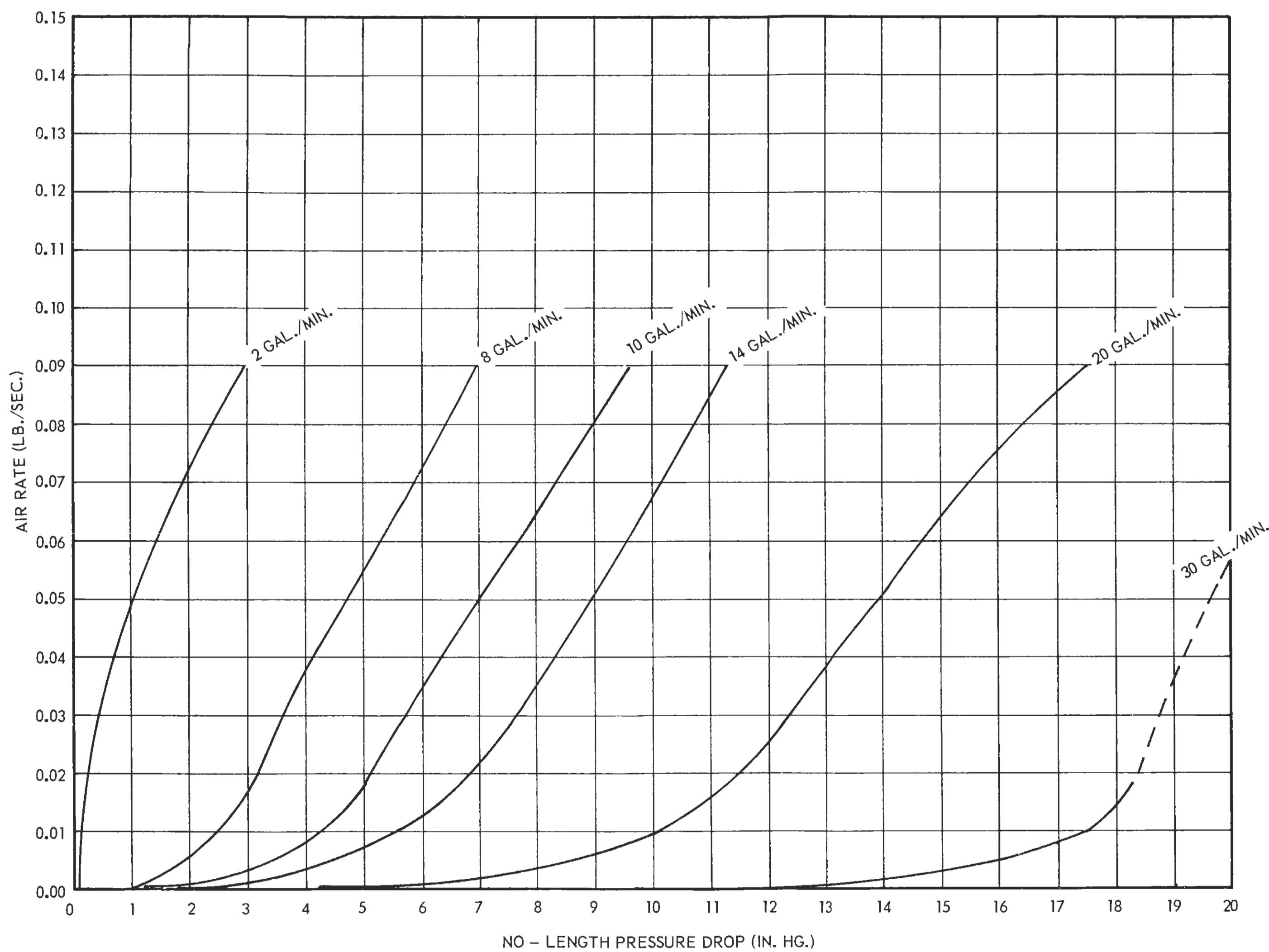


Figure 17. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Plug Disc Globe Valve - One-half Total Turns Closed.

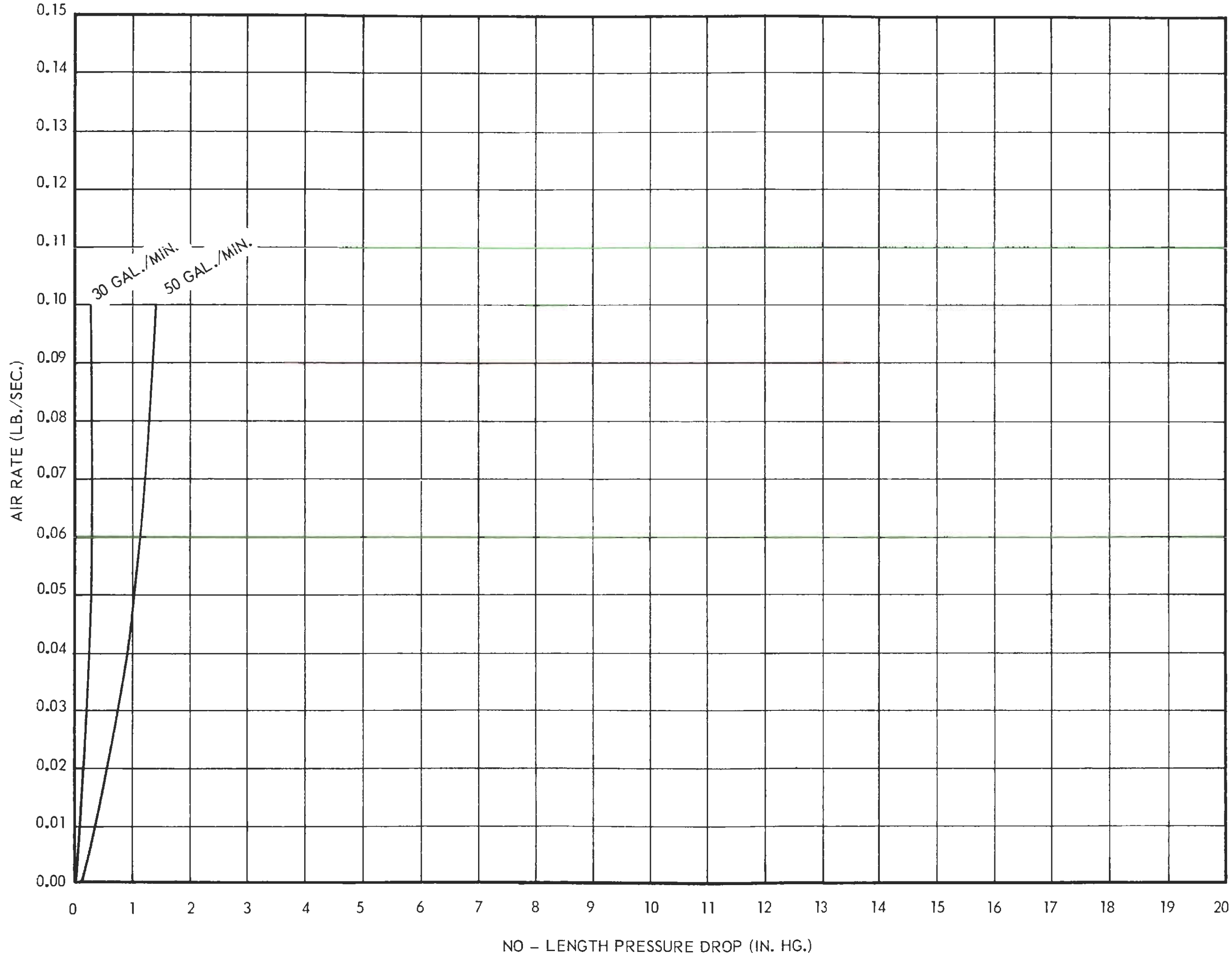


Figure 18. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Gate Valve Wedge Disc - Rising Stem - Full Open.

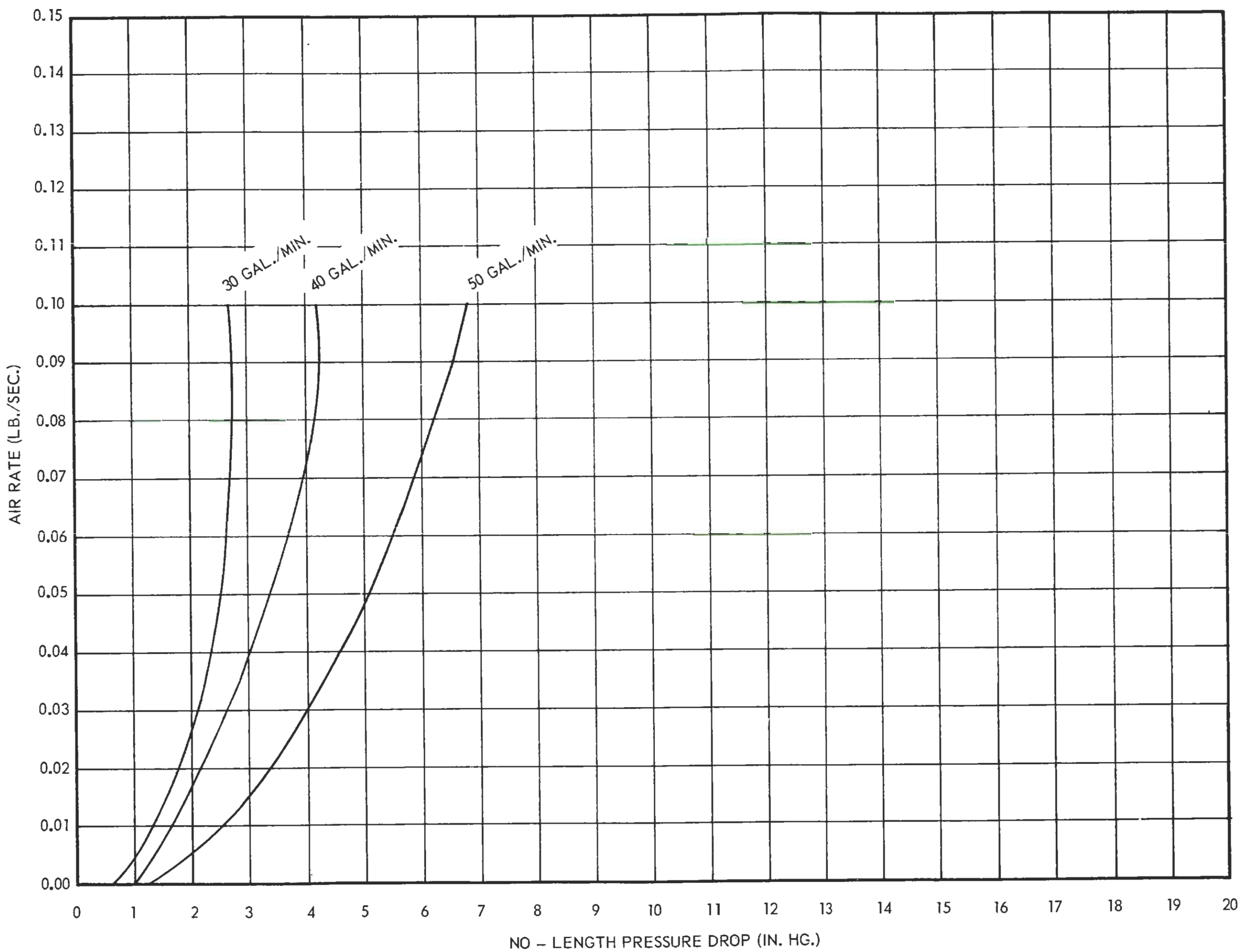


Figure 19. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Gate Valve, Wedge Disc - Rising Stem - One-half Total Turns Closed.

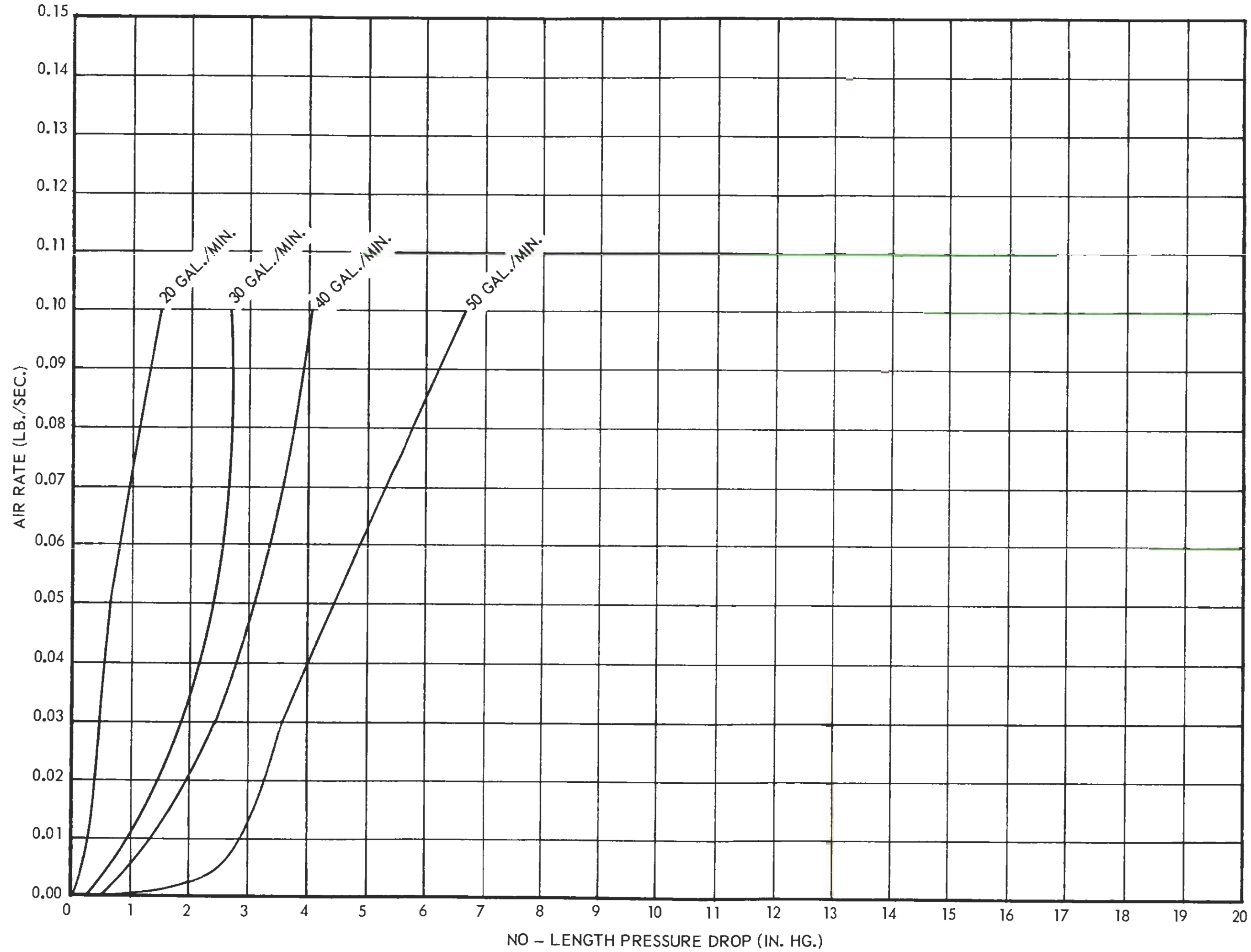


Figure 20. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Y-Pattern Swing Check Valve.

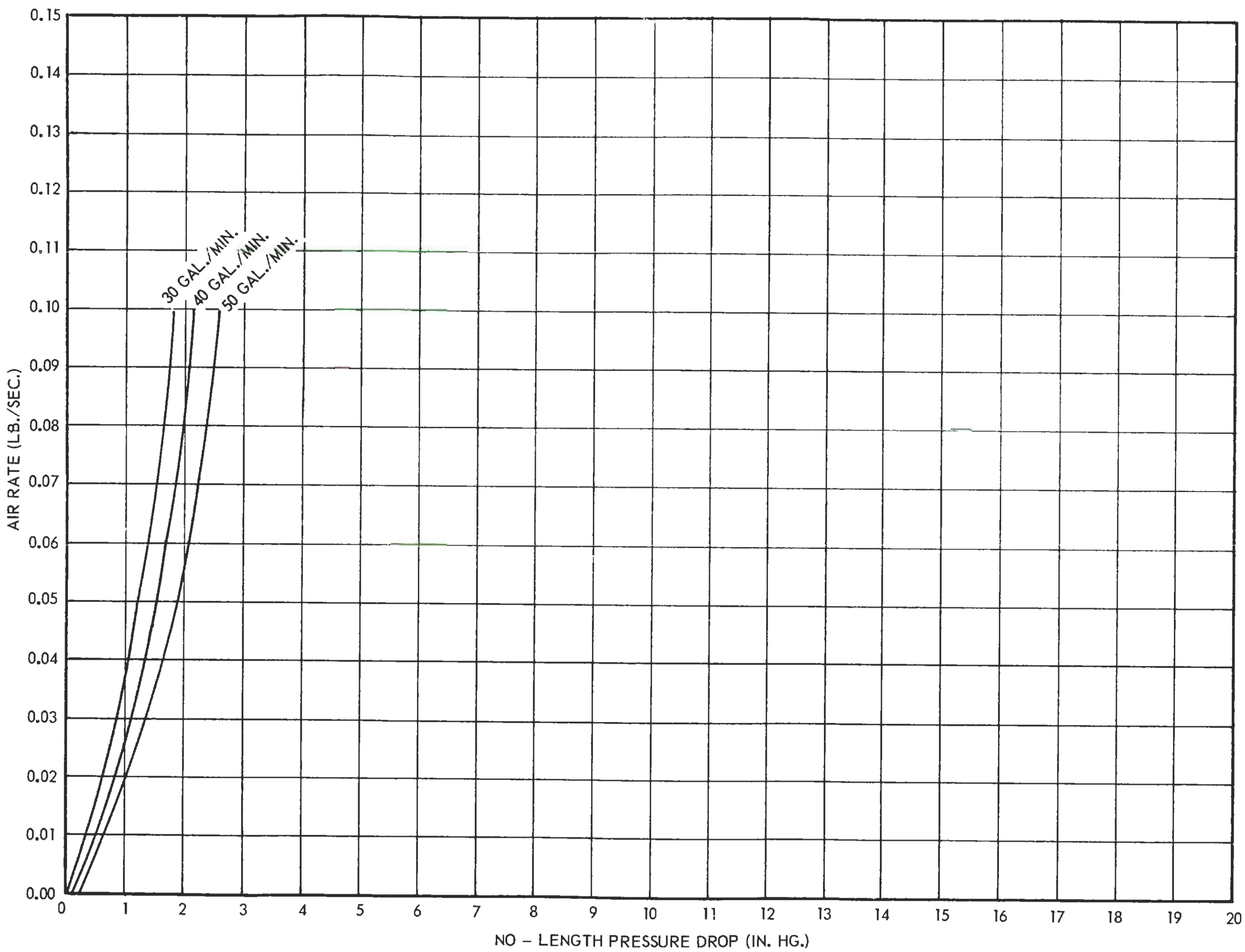


Figure 21. No - Length Pressure Drop Vs. Air Rate at Constant Water Rates, 1 1/2 Inch Iron Gas Line Cock - Full Open.

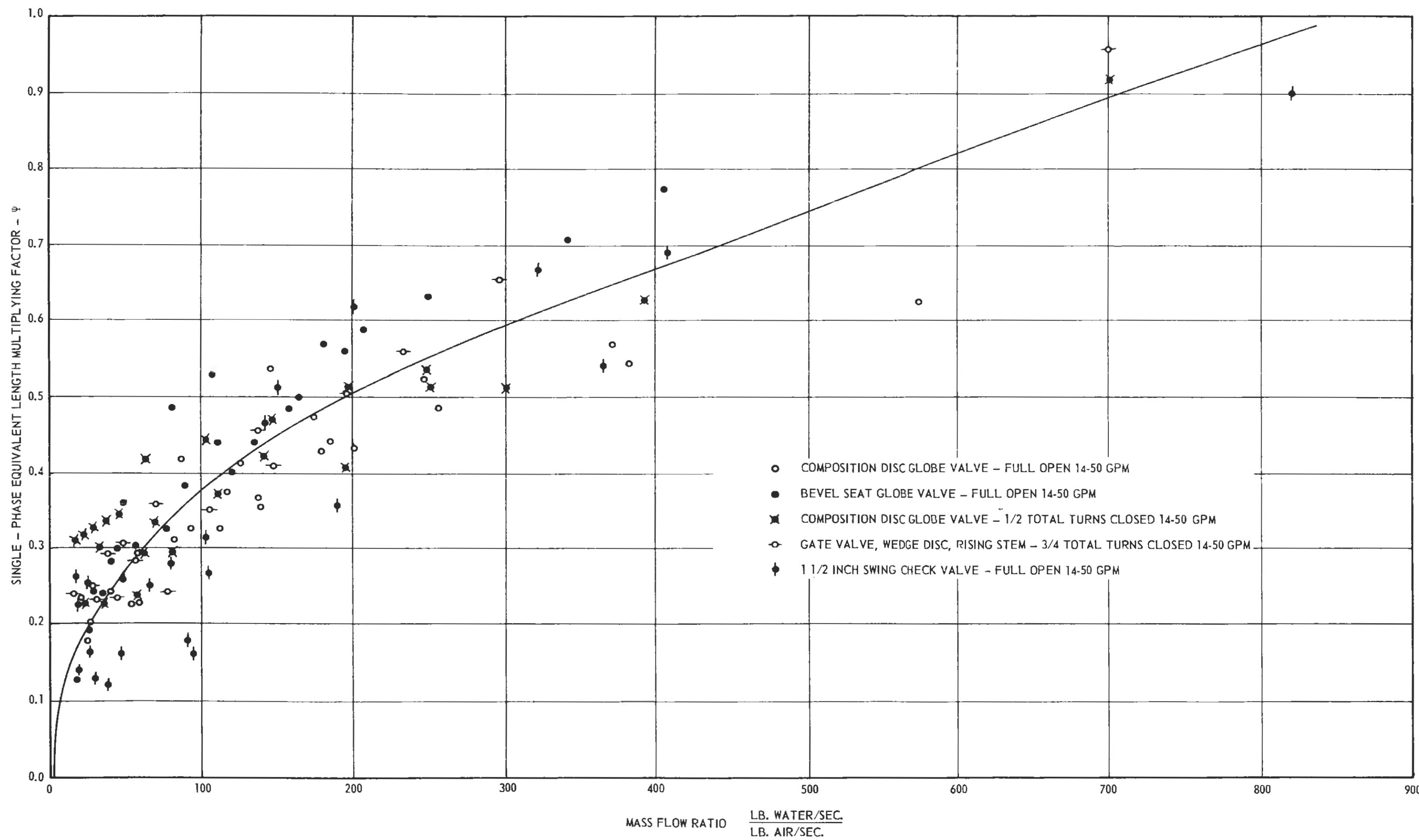


Figure 22. Correlation Curve Showing Single-Phase Equivalent Length Multiplying Factor Vs. Mass Flow Ratio.

A P P E N D I X

APPENDIX I

IDENTIFICATION OF VALVES AND FITTINGS USED IN TESTS

The following 1 1/2 inch valves and fittings were generously donated by the Crane Company for use in the two-phase pressure drop evaluations:

Valve or Fitting	Crane Catalogue No.
1. 150-Pound Brass Globe Valve with Cranite Composition Disc	7
2. 200-Pound Bronze Globe Valve, Plug Disc Type	212P
3. 200-Pound Bronze Globe Valve, Regrinding (Bevel Seat)	70
4. 200-Pound Bronze Gate Valve, Wedge Disc - Rising Stem	422
5. 125-Pound Iron Gas Line Cock with Brass Plug	1232
6. 200-Pound Bronze Y-Pattern Swing Check Valve, Regrinding	36
7. 300-Pound Malleable Iron 90° Elbow	260E
8. 300-Pound Malleable Iron Tee	264E
9. Cast Iron (Galvanized) 90° Long Turn Drainage Elbow	1001

APPENDIX II

BASIC DATA FROM ALL RUNS

Table 3 includes the basic experimental data from all runs made in these tests.

Table 3A. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Calibration Runs, No Valve

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
95	2	0.0114	31	26	0.5	0.5
96	2	0.0268	31	26	0.7	0.6
97	2	0.0452	31	26	0.8	0.5
98	2	0.0620	31	26	1.1	0.5
99	2	0.0997	32	26	1.7	1.0
100	2	0.1156	32	25	2.2	1.0
101	4	0.0143	33	25	1.0	1.0
102	4	0.0268	33	25	1.2	1.0
103	4	0.0452	33	25	1.4	1.0
104	4	0.0688	33	27	1.7	1.0
105	4	0.0843	33	27	2.2	1.0
106	4	0.1150	34	27	3.4	2.0
107	6	0.0165	29	31	1.3	2.0
108	6	0.0278	29	31	1.6	1.5
109	6	0.0453	30	31	2.5	1.7
110	6	0.0636	30	31	2.8	1.7
111	6	0.0491	31	31	2.5	3.0
112	6	0.0946	31	31	3.6	3.0
113	6	0.0793	31	31	3.2	3.0
114	8	0.0145	32	31	1.8	2.6
115	8	0.0293	33	31	2.3	2.0
116	8	0.0477	33	31	3.4	2.5
117	8	0.0652	33	31	3.6	3.0
118	8	0.0924	34	31	4.5	3.0
119	10	0.0146	34	30	2.0	3.0
120	10	0.0295	35	31	3.2	2.0
121	10	0.0488	35	31	4.0	3.0
122	10	0.0663	35	31	4.6	3.5
123	10	0.1170	35	31	6.9	5.5
124	10	0.0926	35	31	6.4	4.5
125	12	0.0152	35	31	2.3	1.0
126	12	0.0299	35	31	3.8	1.8
127	12	0.0494	35	31	4.9	2.3
128	12	0.0670	35	31	5.5	4.0
129	12	0.0888	35	31	7.1	5.0
130	12	0.1166	35	31	8.1	7.5
131	14	0.0154	35	31	3.0	1.2
132	14	0.0301	35	31	4.1	2.6
133	14	0.0501	31	31	6.0	3.5
134	14	0.0688	31	31	7.1	4.7
135	14	0.0910	35	31	8.2	7.5
136	14	0.1107	35	31	9.4	8.0
137	10	0.1012	31	31	6.1	4.5

Table 3A. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Calibration Runs, No Valve

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
138	20	0.0164	25	25	4.3	3.1
139	20	0.0301	25	25	4.9	4.1
140	20	0.0523	25	25	8.0	7.0
141	20	0.0729	25	25	9.0	8.5
142	20	0.1168	25	25	11.9	12.5
143	30	0.0156	25	25	6.1	5.3
144	39	0.0329	25	25	8.3	8.0
145	30	0.0546	25	25	11.2	10.5
146	30	0.0778	25	25	13.4	14.0
147	30	0.1048	25	25	15.0	12.0
148	30	0.0714	25	25	11.8	12.5
149	40	0.0150	25	25	8.2	8.0
150	40	0.0290	25	25	10.1	11.0
151	40	0.0538	25	25	14.1	15.8
152	40	0.0736	25	25	16.5	18.5
153	40	0.0856	25	25	18.1	20.5
154	40	0.0946	25	25	19.2	22.5
155	50	0.0145	25	25	10.0	11.0
156	50	0.0264	25	25	12.8	14.0
157	50	0.0500	25	25	15.6	19.0
158	20	0.0720	28	26	9.6	8.7
159	20	0.1010	29	26	11.4	12.0
160	20	0.0874	29	26	10.4	11.3
161	20	0.0913	29	26	10.0	10.0
162	30	0.0644	29	26	11.9	12.5
163	30	0.0773	31	31	13.3	14.3
164	30	0.0936	31	31	15.4	15.8
165	30	0.1069	31	31	16.5	17.5
166	40	0.0756	32	31	17.1	18.8
167	40	0.0921	32	31	18.5	20.8
168	40	0.1095	33	30	19.8	22.5

Table 3B. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Composition Disc Globe Valve Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
169	2		26		.5	
170	4		27		.2	
171	6		27		.3	
172	8		27		.4	
173	10		27		.6	
174	12		27		.8	
175	14		27		.9	
176	20		27		1.9	
177	30		27		4.1	
178	40		27		7.1	
179	50		28		10.5	
180	60		28		15.3	
202	2	0.0110	29	26	0.6	0.0
203	2	0.0190	29	26	0.7	0.0
204	2	0.0372	29	26	0.8	0.0
205	2	0.0530	29	26	1.2	0.0
206	2	0.0618	29	26	1.3	0.0
207	2	0.0932	29	26	2.4	0.0
208	2	0.1260	29	26	4.3	1.5
209	4	0.0150	29	26	1.3	0.0
210	4	0.0205	30	26	1.5	0.0
211	4	0.0378	30	26	1.6	0.0
212	4	0.0625	30	26	2.3	0.8
213	4	0.1040	30	26	5.4	2.8
214	4	0.1142	30	26	5.9	3.1
215	6	0.0125	30	26	1.8	0.4
216	6	0.0210	30	26	2.0	0.0
217	6	0.0387	30	26	2.7	0.0
218	6	0.0647	30	26	3.9	1.5
219	6	0.0951	30	26	5.6	3.6
220	6	0.1060	31	26	6.7	4.0
221	6	0.0880	31	27	4.7	2.0
222	8	0.0130	31	27	2.3	0.5
223	8	0.0222	31	27	2.7	0.8
224	8	0.0400	31	27	3.7	2.5
225	8	0.0660	31	27	5.5	2.8
226	8	0.0975	31	27	7.3	5.0
227	8	0.1110	31	27	8.5	6.0
228	10	0.0132	33	29	3.3	1.0
229	10	0.0213	33	29	3.6	1.3
230	10	0.0406	33	29	4.7	2.0

Table 3B. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Composition Disc Globe Valve Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
231	10	0.0670	33	29	6.5	3.5
232	10	0.0891	33	29	8.7	6.0
233	10	0.1175	33	29	10.2	7.0
234	10	0.0983	33	29	9.2	6.5
235	12	0.0133	33	29	3.3	1.0
236	12	0.0220	33	29	4.2	2.0
237	12	0.0410	33	29	5.9	3.5
238	12	0.0684	33	29	8.0	5.0
239	12	0.0925	33	29	9.8	7.5
240	12	0.1095	33	29	11.6	8.0
241	14	0.0135	27	33	4.2	1.5
242	14	0.0226	27	33	5.1	3.0
243	14	0.0420	27	33	6.9	4.5
244	14	0.0735	27	32	9.4	6.5
245	14	0.0930	27	32	12.0	8.0
246	14	0.1150	27	32	12.9	10.0
247	20	0.0140	27	31	5.7	3.5
248	20	0.0235	28	31	7.5	4.5
249	20	0.0490	28	31	10.2	7.0
250	20	0.0815	28	31	13.7	11.0
251	20	0.1020	28	31	17.5	14.0
252	30	0.0160	29	32	10.0	7.0
253	30	0.0305	29	32	12.5	9.5
254	30	0.0450	29	32	15.6	12.0
255	30	0.0720	29	32	19.3	16.5
256	30	0.1010	29	32	22.5	20.5
257	30	0.1010	30	32	22.4	20.0
258	40	0.0150	30	32	14.6	11.5
259	40	0.0300	30	32	17.6	14.5
260	40	0.0435	30	32	21.0	17.5
261	40	0.0680	30	32	25.2	22.5
262	40	0.0225	30	32	16.5	13.0
263	40	0.1073	30	32	28.6	28.0
264	50	0.0120	31	32	18.3	15.0
265	50	0.0245	31	32	22.4	18.5
266	50	0.0390	31	32	25.0	22.0
267	50	0.0506	31	32	26.6	25.0
268	50	0.0610	31	32	28.2	27.0

Table 3C. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Composition Disc Globe Valve 1/2 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
181	2		28		0.2	
182	4		28		0.2	
183	6		28		0.2	
184	8		28		0.4	
185	10		28		0.6	
186	12		28		0.9	
187	14		28		1.2	
188	20		28		2.1	
189	30		28		4.8	
190	40		28		8.6	
200	50		28		13.0	
201	60		28		19.8	
269	2	0.0120	32	32	0.7	0.0
270	2	0.0200	33	33	0.7	0.0
271	2	0.0370	33	33	1.0	0.0
272	2	0.0685	33	33	1.8	0.0
273	2		33	33	3.3	0.0
274	4	0.0130	33	33	1.1	0.0
275	4	0.0270	33	33	1.5	0.0
276	4	0.0497	34	33	2.3	0.0
277	4	0.0770	34	33	3.5	1.0
278	4	0.1336	34	33	5.5	2.5
279	6	0.0130	34	33	1.8	0.0
280	6	0.0288	34	33	2.3	0.0
281	6	0.0485	35	33	3.3	1.5
282	6	0.0790	35	33	5.5	2.5
283	6	0.1145	35	33	7.5	4.5
284	8	0.0130	35	33	2.4	0.0
285	8	0.0285	35	33	3.2	0.0
286	8	0.0500	35	33	4.4	2.5
287	8	0.0750	35	33	6.1	4.5
288	8	0.1052	35	33	8.3	6.0
289	10	0.0135	35	33	2.6	0.7
290	10	0.0292	35	33	4.4	1.5
291	10	0.0505	35	33	5.9	3.0
292	10	0.0775	35	33	7.9	5.0
293	10	0.1052	35	33	10.2	7.5
294	12	0.0135	35	33	4.1	1.7
295	12	0.0295	35	33	4.9	3.0
296	12	0.0525	35	33	7.3	5.0
297	12	0.0785	35	33	10.0	7.5

Table 3C. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Composition Disc Globe Valve 1/2 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
298	12	0.1092	35	34	12.5	8.0
299	14	0.0135	35	34	4.4	2.0
300	14	0.0310	35	34	6.9	4.0
301	14	0.0540	35	34	8.3	5.0
302	14	0.0810	35	34	11.4	8.0
303	14	0.1100	35	34	13.8	12.0
304	14	0.0881	35	34	11.8	9.5
305	20	0.0145	27	25	6.2	3.8
306	20	0.0245	27	25	8.5	6.0
307	20	0.0460	27	25	11.5	7.5
308	20	0.0860	27	25	15.8	12.5
309	20	0.1193	27	25	19.3	15.5
310	30	0.0163	27	25	11.6	8.0
311	30	0.0295	27	25	14.5	10.5
312	30	0.0513	27	25	18.8	14.0
313	30	0.0895	28	25	23.8	19.0
314	30	0.1050	28	25	26.0	22.5
315	40	0.0187	28	25	17.2	12.0
316	40	0.0280	28	25	20.1	16.0
317	40	0.0540	28	25	25.6	21.5
318	40	0.0810	28	25	29.0	26.0
319	40	0.0960	28	25	29.6	27.5
320	50	0.0080	29	25	21.8	15.5
321	50	0.0177	29	25	24.2	17.8
322	50	0.0280	29	25	27.4	21.5
323	50	0.0400	29	25	29.1	25.0

Table 3D. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Bevel Seat Globe Valve, Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
324	2		27		0.2	
5	4		27		0.3	
6	6		27		0.4	
7	10		27		0.6	
8	14		27		1.1	
9	20		27		2.0	
330	30		27		4.5	
1	40		27		8.2	
2	50		27		12.9	
3	60		29		19.0	
4	50		29		12.8	
5	40		29		8.3	
6	30		29		4.7	
7	20		29		2.1	
8	14		29		1.0	
9	10		29		0.6	
340	6		29		0.2	
1	4		29		0.0	
2	2		29		0.0	
353	2		30	33	0.5	0.0
4	2		30	33	0.7	0.0
5	2		30	33	0.8	0.0
6	2		30	33	1.6	0.0
7	2		30	32	3.0	0.0
8	4		31	32	1.2	0.0
9	4		32	32	1.0	0.0
360	4		32	32	1.0	0.0
1	4		32	32	2.8	0.8
2	4		32	32	5.2	2.1
3	6		32	32	1.6	0.0
4	6		32	32	2.0	0.0
5	6		32	32	2.4	1.0
6	6		32	32	4.0	2.0
7	6		32	32	5.9	3.5
8	10		27	33	3.3	1.5
9	10		27	33	4.2	2.0
370	10		27	33	4.6	3.0
1	10	0.0735	28	33	7.1	5.0
2	10	0.1055	28	33	9.4	6.5
3	14	0.0135	28	32	4.8	2.0
4	14	0.0240	29	32	5.7	3.5

Table 3D. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Bevel Seat Globe Valve, Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
5	14	0.0415	29	32	7.1	5.0
6	14	0.0750	29	32	9.6	7.5
377	14	0.1095	29	32	12.0	9.0
8	20	0.0145	30	32	6.5	4.5
9	20		30	32	8.7	6.0
380	20	0.0455	30	32	12.2	7.5
1	20		30	32	14.3	12.0
2	20		26	27	16.5	14.0
3	30	0.0165	26	27	11.8	8.0
4	30	0.0270	26	27	13.5	10.0
5	30		26	27	17.8	13.5
6	30		27	27	21.5	18.0
7	30	0.1020	27	27	24.2	21.0
8	30		28	26	22.7	19.0
9	40		28	26	17.3	12.5
390	40	0.0305	28	26	20.2	16.0
1	40	0.0500	28	26	24.0	20.0
2	40	0.0725	28	26	27.2	24.5
3	40	0.0970	28	26	29.2	29.0
4	50	0.0170	28	27	23.8	19.0
5	50	0.0340	28	27	37.0	23.5
6	50	0.0425	28	27	28.4	24.5
7	50	0.0520	28	27	29.2	27.5
8	50	0.0580	28	27	29.5	29.0
9	60	0.0065	29	28	27.8	20.0
400	60	0.0090	29	28	28.3	21.0
401	60	0.0110	29	28	29.1	22.0
2	60	0.0135	29	28	29.4	23.0

Table 3E. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Bevel Seat Globe Valve, 1/2 Total Turns, Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
343	2		28		0.0	
4	4		28		0.3	
5	6		28		0.5	
6	10		28		1.0	
7	14		28		1.6	
8	20		28		2.9	
9	30		28		6.9	
350	40		29		11.8	
1	50		29		18.5	
2	60		29		27.0	
403	2		30	28	0.8	0.0
4	2	0.0220	31	29	1.0	0.0
5	2	0.0375	31	29	1.2	0.0
6	2	0.0685	31	29	2.0	0.0
7	2	0.1025	31	29	3.6	0.5
8	4	0.0130	31	29	1.6	0.0
9	4	0.0225	32	29	2.2	0.0
410	4	0.0375	32	29	2.4	0.0
11	4	0.0690	32	29	3.8	1.0
12	4	0.1030	32	29	5.7	2.5
13	6	0.0130	27	32	2.2	0.8
14	6	0.0225	27	32	2.6	0.9
15	6	0.0390	27	32	3.4	1.6
16	6	0.0650	28	31	4.7	2.0
17	6	0.1045	28	31	7.4	3.0
18	10	0.0135	28	31	3.8	1.3
19	10	0.0235	28	31	4.7	1.7
420	10	0.0410	29	31	5.7	2.5
1	10	0.0675	29	31	7.9	6.3
2	10	0.1135	29	31	10.6	8.0
3	14	0.0140	30	31	5.3	2.0
4	14	0.0240	30	31	6.5	4.0
5	14	0.0430	30	31	8.3	6.8
6	14	0.0695	30	31	10.6	7.5
427	14	0.1160	31	31	15.0	12.5
8	20	0.0150	31	31	8.5	5.0
9	20	0.0270	31	31	10.2	7.3
430	20	0.0465	31	31	13.7	9.4
1	20	0.0725	31	31	16.1	12.5
2	20	0.1000	31	31	19.9	16.0
3	30	0.0145	31	31	13.9	9.0

Table 3E. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Bevel Seat Globe Valve, 1/2 Total Turns, Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_C °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
4	30	0.0280	31	31	17.0	12.0
5	30	0.0490	31	31	21.2	16.7
6	30	0.0790	31	31	24.4	21.5
7	30	0.0980	31	31	27.2	24.0
8	40	0.0165	27	32	21.8	15.0
9	40	0.0315	27	32	25.2	20.1
1	40	0.0550	27	32	28.7	25.0
2	40	0.0680	27	32	29.2	28.0
3	40	0.0795	27	32	29.5	29.0
4	50	0.0060	28	32	26.0	17.0
5	50	0.0090	28	32	27.2	17.5
6	50	0.0105	28	32	28.2	20.0
7	50	0.0150	28	32	29.2	21.0

Table 3F. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Plug Disc Globe Valve, Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
448	2		29		0.1	
9	4		29		0.1	
450	6		29		0.2	
1	8		29		0.3	
2	10		29		0.5	
3	12		29		0.9	
4	14		30		1.0	
5	20		30		1.9	
6	30		30		4.3	
7	40		30		8.1	
8	50		30		12.1	
9	60		31		17.8	
565	2	0.0120	24	20	0.6	0.0
6	2	0.0220	24	20	0.6	0.0
7	2	0.0375	24	20	0.8	0.0
8	2	0.0620	24	20	1.4	0.0
9	2	0.0870	24	20	2.2	0.0
570	2	0.1035	24	20		0.5
1	4	0.0125	24	20	0.8	0.0
2	4	0.0230	24	20	1.0	0.0
3	4	0.0385	24	20	1.6	0.0
4	4	0.0630	24	20	2.8	0.0
5	4	0.0870	24	20	3.6	1.2
6	4	0.0950	24	20	4.3	1.5
7	8	0.0130	24	20	2.4	0.0
8	8	0.0235	24	20	2.8	1.0
9	8	0.0395	24	20	3.9	1.5
580	8	0.0655	24	20	5.5	3.0
1	8	0.0885	24	20	6.9	5.0
2	8	0.1080	24	20	8.0	6.0
3	10	0.0135	24	20	3.3	1.0
4	10	0.0240	24	20	3.7	2.0
5	10	0.0410	24	20	4.7	3.0
6	10	0.0675	24	20	0.1	5.0
7	10	0.0900	24	20	9.0	6.0
8	12	0.0135	24	20	3.7	1.0
589	12	0.0243	24	20	4.3	2.0
590	12	0.0420	24	20	5.9	4.0
1	12	0.0680	24	20	8.6	5.0
2	12	0.0925	24	20	10.0	8.0
3	12	0.1015	24	20	11.9	9.0

Table 3F. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Plug Disc Globe Valve, Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to\ Test\ Section}$ psig.
4	14	0.0140	24	20	4.3	2.0
5	14	0.0265	24	20	6.2	3.0
6	14	0.0430	24	20	7.3	5.0
7	14	0.0705	24	20	10.6	7.0
8	14	0.0940	24	20	10.6	9.0
9	20	0.0150	24	21	7.3	4.5
600	20	0.0265	25	21	9.3	6.0
1	20	0.0465	25	21	12.3	8.5
2	20	0.0750	25	21	15.2	12.0
3	20	0.1005	25	21	18.0	14.0
4	30	0.0165	25	21	12.1	8.5
5	30	0.0305	25	21	15.2	11.0
6	30	0.0520	25	21	18.6	15.0
7	30	0.0825	25	21	24.4	19.0
8	30	0.1090	25	21	26.8	25.6
9	40	0.0185	25	21	29.2	14.5
610	40	0.0340	25	21	22.6	18.0
11	40	0.0580	25	21	27.2	23.0
12			25	21		
613	50	0.0205	25	21	26.8	20.5
14	50	0.0285	25	21	28.1	22.0
15	50	0.0185	25	21	25.0	18.0
16	50	0.0080	25	21	22.0	16.0
17	50	0.0055	25	21	21.4	15.3

Table 3G. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Plug Disc Globe Valve, 1/2 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	(P)$_{exp.}$ in.Hg.	P inlet to Test Section psig.
460	2		31		0.2	
1	4		31		0.3	
2	6		32		0.5	
3	8		32		0.8	
4	10		32		1.3	
5	12		32		1.6	
6	14		32		2.4	
7	20		32		5.1	
8	30		32		11.6	
9	40		32		20.4	
470	45		32		25.8	
1	48		32		28.6	
527	2	0.0130	26	26	0.1	0.0
8	2	0.0220	26	26	0.5	0.0
9	2	0.0380	26	26	1.4	0.0
530	2	0.0635	26	26	2.8	0.0
1	2	0.0910	26	26	4.2	1.0
2	2	0.0940	26	26	5.1	2.0
3	4	0.0125	27	25	1.4	0.0
4	4	0.0225	27	25	1.8	0.0
5	4	0.0380	28	25	2.8	0.0
6	4	0.0645	28	25	4.8	1.0
7	4	0.0925	28	25	7.3	3.0
8	4	0.1060	28	25	9.2	5.0
9	8	0.0135	26	28	4.4	2.0
540	8	0.0235	26	28	5.7	3.0
1	8	0.0405	26	28	6.7	3.5
2	8	0.0675	27	27	9.2	6.0
3	8	0.0900	27	27	11.9	8.0
4	8	0.1090	27	27	14.5	9.0
5	10	0.0140	28	27	7.1	3.0
6	10	0.0245	28	27	8.1	5.0
7	10	0.0420	28	27	9.2	6.0
8	10	0.0695	28	27	13.3	8.0
9	10	0.0920	28	27	15.4	11.0
550	14	0.0145	29	27	9.6	6.0
551	14	0.0255	29	27	11.2	7.0
2	14	0.0450	29	27	14.1	10.0
3	14	0.0730	29	27	17.6	12.0

Table 3G. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Plug Disc Globe Valve, 1/2 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	(P)$_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
4	14	0.0960	29	27	20.2	15.0
5	14	0.0855	29	27	18.6	13.0
6	20	0.0160	29	27	15.2	10.0
7	20	0.0285	29	27	16.8	11.5
8	20	0.0505	29	27	22.0	17.0
9	20	0.0800	29	27	26.0	21.0
560	30	0.0170	30	27	25.4	18.0
1	30	0.0330	30	27	26.2	19.0
2	30	0.0075	30	27	23.6	15.0
3	30	0.0250	30	27	24.6	20.0
4	40		31	27		0.0

Table 3H. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Y-Pattern Swing Check Valve

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P inlet to Test Section psig.
793	2		20		0.0	
794	4		20		0.0	
795	6		20		0.0	
796	8		20		0.0	
797	10		20		0.0	
798	12		20		0.0	
799	14		20		0.0	
800	20		20		1.0	
801	30		20		2.2	
802	40		20		4.2	
803	50		20		6.3	
804	60		20		9.4	
618	2	0.0120	22	22	0.5	0.0
619	2	0.0220	22	22	0.6	0.0
620	2	0.0380	22	22	0.8	0.0
621	2	0.0630	22	22	1.2	0.0
622	2	0.0855	22	22	1.8	0.0
623	2	0.1035	22	22	2.4	0.0
624	4	0.0130	22	22	0.8	0.0
625	4	0.0220	22	22	1.2	0.0
626	4	0.0380	22	22	1.4	0.0
627	4	0.0630	22	22	2.2	0.0
628	4	0.0875	22	22	3.0	0.5
629	4	0.0960	22	22	3.4	1.0
630	8	0.0180	23	21	1.6	0.0
631	8	0.0235	23	21	2.2	0.0
632	8	0.0405	23	21	3.1	0.5
633	8	0.0655	23	21	4.5	2.5
634	8	0.0975	23	21	6.3	4.0
635	10	0.0135	24	21	2.6	0.0
636	10	0.0240	24	21	3.1	1.6
637	10	0.0405	24	21	3.9	2.0
638	10	0.0665	24	21	6.1	4.5
639	10	0.0890	24	21	6.7	5.0
640	10	0.0980	24	21	7.3	5.5
641	14	0.0135	24	21	2.8	1.0
642	14	0.0240	24	21	3.7	2.5
643	14	0.0420	24	21	5.3	3.5
644	14	0.0695	24	21	7.7	5.5
645	14	0.0930	24	21	9.6	7.5
646	14	0.1100	24	21	10.6	8.5
647	14	0.1010	24	21	10.2	8.0

Table 3H. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Y-Pattern Swing Check Valve

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
648	20	0.0140	25	22	4.3	3.0
649	20	0.0260	25	22	5.7	4.0
650	20	0.0450	25	22	7.9	6.5
651	20	0.0740	25	22	10.4	10.0
652	20	0.0970	25	22	12.5	12.0
653	20	0.1065	25	22	13.9	13.5
654	30	0.0130	26	22	6.5	6.0
655	30	0.0280	26	22	9.6	7.5
656	30	0.0495	26	22	12.7	10.5
660	30	0.0795	26	22	16.0	14.5
661	30	0.1140	26	22	20.2	19.0
662	30	0.1020	26	22	18.4	18.0
663	40	0.0175	21	22	10.8	9.2
664	40	0.0310	21	22	12.9	11.5
665	40	0.0540	21	22	17.2	16.5
666	40	0.0540	21	22	17.2	16.5
667	40	0.0980	22	22	21.8	22.5
668	50	0.0080	22	22	11.7	10.7
669	50	0.0190	22	22	14.1	13.0
670	50	0.0340	22	22	17.4	17.0
671	50	0.0480	22	22	19.8	19.7
672	50	0.0695	22	22	23.2	23.0
673	50	0.0760	22	22	24.0	25.0
674	60	0.0060	24	22	14.4	13.5
675	60	0.0130	24	22	17.0	15.7
676	60	0.0230	24	22	19.6	19.0

Table 3I. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Iron Gas Line Cock - Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P inlet to Test Section psig.
727	2		24		0.0	
728	4		24		0.1	
729	6		24		0.1	
730	8		24		0.2	
731	10		24		0.2	
732	12		24		0.3	
733	14		24		0.5	
734	20		25		0.6	
735	30		25		1.8	
736	40		25		3.4	
737	50		25		5.3	
738	60		25		7.9	
677	2	0.0130	21	26	0.2	0.0
678	2	0.0270	21	26	0.5	0.0
679	2	0.0370	21	26	0.6	0.0
680	2	0.0620	21	26	1.0	0.0
681	2	0.0840	21	26	1.4	0.0
682	2	0.1025	21	26	2.0	0.0
683	4	0.0130	22	26	0.5	0.0
684	4	0.0230	22	26	0.6	0.0
685	4	0.0385	22	26	1.2	0.0
686	4	0.0635	22	26	1.8	0.0
687	4	0.0864	22	26	2.4	0.5
688	4	0.0034	22	26	3.0	0.7
689	8	0.0132	23	25	1.4	0.0
690	8	0.0230	23	25	2.0	0.0
691	8	0.0390	23	25	2.8	1.0
692	8	0.0645	23	25	4.0	2.0
693	8	0 0875	23	25	4.7	3.0
694	8	0.0953	23	25	5.3	3.5
695	10	0.0132	23	25	2.0	0.0
696	10	0.0230	23	25	3.0	0.5
697	10	0.0410	23	25	3.7	2.0
698	10	0.0655	23	25	5.1	3.0
699	10	0.0885	23	25	5.9	4.0
700	10	0.0975	24	25	6.1	5.0
701	14	0.0135	24	25	2.8	0.7
702	14	0.0240	24	25	3.9	2.0
703	14	0.0414	24	25	5.1	3.5
704	14	0.0684	24	25	6.7	5.0

Table 31. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Iron Gas Line Cock - Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
705	14	0.0912	24	25	8.2	6.0
706	14	0.1000	24	25	9.0	7.0
707	20	0.0140	25	25	3.9	2.5
708	20	0.0252	25	25	5.9	3.5
710	20	0.0723	25	25	10.2	8.0
711	20	0.0929	25	25	11.5	11.0
712	20	0.1050	25	25	11.9	11.0
713	30	0.0155	27	25	6.3	5.0
714	30	0.0182	27	25	8.6	7.0
715	30	0.0500	27	25	11.5	10.5
716	30	0.0734	27	25	14.6	14.0
717	30	0.1035	27	25	17.2	16.0
718	40	0.0170	28	25	9.4	8.5
719	40	0.0314	28	25	12.1	11.5
720	40	0.0538	28	25	15.6	15.0
721	40	0.0848	28	25	19.8	20.0
722	50	0.0175	29	25	12.7	12.0
723	50	0.0344	23	22	15.0	15.0
724	50	0.0586	23	22	18.8	18.5
725	50	0.0905	23	22	23.2	25.0
726	50	0.0687	23	22	20.4	22.5

Table 3J. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Iron Gas Line Cock - 1/2 Turn Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
739						
740	2		25	24	0.0	
741	4		25	24	0.1	
742	6		25	24	0.2	
743	8		25	24	0.6	
744	10		25	24	1.0	
745	12		25	24	1.6	
746	14		25	24	2.3	
747	20		26	24	4.7	
748	30		26	24	11.6	
749	40		26	24	21.3	
750	50		26	24	29.4	
751	45		26	24	26.4	
752	2	0.0125	27	24	0.5	0.0
753	2	0.0205	25	24	0.7	0.0
754	2	0.0380	27	24	1.2	0.0
755	2	0.0625	27	24	2.4	0.0
756	2	0.8550	27	24	4.4	0.0
758	4	0.0125	27	24	0.8	0.0
759	4	0.0205	27	24	1.8	0.0
760	4	0.0385	27	24	3.0	0.0
761	4	0.0635	27	24	4.3	0.5
762	4	0.0875	27	24	6.1	2.0
763	4	0.1045	27	23	8.1	3.5
764	8	0.0135	20	23	3.3	1.0
765	8	0.0220	20	23	4.1	2.0
766	8	0.0405	20	23	5.7	2.5
767	8	0.0670	20	23	7.7	4.0
768	8	0.0905	20	23	10.6	7.0
769	8	0.1100	20	23	12.5	8.0
770	10	0.0135	22	23	5.3	2.5
771	10	0.0230	22	23	6.7	4.0
772	10	0.0430	22	23	9.0	6.0
773	10	0.0695	22	23	12.3	8.0
774	10	0.0950	22	23	15.6	11.0
775	10	0.1030	22	23	15.8	12.0
776	14	0.0140	23	23	6.7	4.0
777	14	0.0245	23	23	8.7	5.0
778	14	0.0445	23	23	10.6	7.0
779	14	0.0735	23	23	15.6	12.0

Table 3J. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Iron Gas Line Cock - 1/2 Turn Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P inlet to Test Section psig.
780	14	0.0970	23	23	17.0	13.0
781	14	0.1135	23	23	19.6	15.0
782	20	0.0160	23	24	10.8	6.5
783	20	0.0280	23	24	13.5	9.0
784	20	0.0480	23	24	16.2	12.5
785	20	0.0780	23	24	21.6	16.0
786	20	0.0104	23	24	26.6	21.0
787	30	0.0180	24	24	21.0	13.0
788	30	0.0334	24	24	25.0	18.0
789	30	0.0555	24	24	28.2	23.0
790	30	0.0463	24	24	27.2	21.5
791	40	0.0050	24	25	27.4	16.0
792	40	0.0080	24	25	28.6	18.0

Table 3K. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Gate Valve, Wedge Disc, Rising Stem, Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
805	2		18		0.1	
806	4		18		0.2	
807	6		18		0.2	
808	8		18		0.3	
809	10		18		0.3	
810	12		18		0.5	
811	14		19		0.6	
812	20		19		0.9	
813	30		19		2.0	
814	40		19		3.6	
815	50		19		5.3	
816	60		19		7.5	
817	2	0.0120	20	19	0.1	0.0
818	2	0.0215	20	19	0.4	0.0
819	2	0.0375	22	19	0.5	0.0
820	2	0.0630	22	19	0.9	0.0
821	2	0.0840	22	19	1.2	0.0
822	2	0.1046	22	19	1.8	0.0
823	4	0.0120	22	19	0.3	0.0
824	4	0.0215	22	19	0.7	0.0
825	4	0.0385	22	19	1.2	0.0
826	4	0.0630	22	19	14	0.0
827	4	0.0870	22	19	2.2	0.0
828	4	0.1047	22	19	2.8	0.7
829	8	0.0135	22	19	1.2	0.0
830	8	0.0236	22	19	2.0	0.7
831	8	0.0390	22	19	2.8	1.0
832	8	0.0650	22	19	3.6	2.0
833	8	0.0885	22	19	4.9	2.5
834	8	0.1075	22	19	5.3	3.5
835	10	0.0135	23	20	1.8	0.0
836	10	0.0230	23	20	2.2	0.0
837	10	0.0395	23	20	3.8	1.0
838	10	0.0665	23	20	4.8	3.0
839	10	0.0890	23	20	5.5	4.0
840	10	0.1075	23	20	6.1	5.0
841	14	0.0135	24	20	2.4	0.0
842	14	0.0240	24	20	3.4	1.0
843	14	0.0425	24	20	4.9	3.0
844	14	0.0680	24	20	7.1	5.0

Table 3K. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Gate Valve, Wedge Disc, Rising Stem, Full Open

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
845	14	0.0920	24	20	8.3	7.0
846	14	0.1105	24	20	8.6	7.5
847	20	0.0140	24	20	3.6	2.0
848	20	0.0245	24	20	5.1	3.0
849	20	0.0445	24	20	7.3	5.0
850	20	0.0725	24	20	9.8	8.0
851	20	0.0970	24	20	10.6	10.0
852	20	0.1050	24	20	11.5	11.0
853	30	0.0155	25	21	5.7	5.0
854	30	0.0285	25	21	7.7	6.0
855	30	0.0490	25	21	10.0	9.5
856	30	0.0775	25	21	13.3	13.0
857	30	0.1030	25	21	16.0	15.0
858	40	0.0170	26	22	9.0	8.5
859	40	0.0315	26	22	11.2	11.0
860	40	0.0525	26	22	13.7	14.0
861	40	0.0845	26	22	18.0	19.0
862	40	0.1020	27	22	22.0	20.0
863	50	0.0185	27	22	11.5	11.5
864	50	0.0340	27	22	13.8	15.0
865	50	0.0575	27	22	18.0	20.0
866	50	0.0900	27	22	21.6	25.0

Table 3L. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Gate Valve, Wedge Disc, Rising Stem, 1/2 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
867	2		21		0.1	
868	4		21		0.2	
869	6		21		0.3	
870	8		21		0.4	
871	10		21		0.4	
872	12		21		0.5	
873	14		21		0.7	
874	20		22		1.1	
875	30		22		2.6	
876	40		22		4.6	
877	50		22		6.9	
878	60		22		9.9	
879	2	0.0110	23	23	0.5	0.0
880	2	0.0216	23	23	0.7	0.0
881	2	0.0310	23	23	0.9	0.0
882	2	0.0613	23	23	1.2	0.0
883	2	0.0845	23	23	1.8	0.0
884	2	0.1032	24	23	2.4	0.0
885	4	0.0110	24	23	0.5	0.0
886	4	0.0216	24	23	0.9	0.0
887	4	0.0385	24	23	1.2	0.0
888	4	0.0613	24	23	1.6	0.0
889	4	0.0860	24	23	2.2	0.0
890	4	0.1038	24	23	3.4	2.0
891	8	0.0120	24	23	1.8	0.0
892	8	0.0217	24	23	2.2	0.0
893	8	0.0386	24	23	2.8	1.5
894	8	0.0650	25	23	3.8	2.0
895	8	0.0875	25	23	5.3	3.5
896	8	0.1064	25	23	6.3	4.0
897	10	0.0130	25	23	2.2	0.0
898	10	0.0232	25	23	2.6	1.0
899	10	0.0404	25	23	4.1	2.5
900	10	0.0670	25	23	5.5	3.0
901	10	0.0900	25	23	6.6	4.0
902	10	0.1060	25	23	8.1	5.0
903	14	0.0132	26	27	3.9	2.0
904	14	0.0337	26	22	4.0	2.5
905	14	0.0425	26	27	5.7	4.0
906	14	0.0676	26	22	7.3	6.0

Table 3L. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Gate Valve, Wedge Disc, Rising Stem, 1/2 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
907	14	0.0920	26	22	7.2	7.0
908	14	0.1064	26	22	9.6	7.0
909	20	0.0137	26	22	4.1	2.5
910	20	0.0137	26	22	4.1	2.5
911	20	0.0436	26	22	8.7	6.0
912	20	0.0723	26	22	10.0	7.5
913	20	0.0958	26	22	11.7	11.0
914	20	0.1129	26	22	13.1	12.0
915	30	0.0152	27	23	7.3	6.0
916	30	0.0285	27	23	10.0	7.5
917	30	0.0500	27	23	12.9	10.5
918	30	0.0794	27	23	15.9	15.0
919	30	0.0955	27	23	17.5	17.0
920	40	0.0171	27	23	11.6	10.0
921	40	0.0317	27	23	13.3	11.5
922	40	0.0544	27	23	17.5	16.0
923	40	0.0858	27	23	21.6	21.0
924	40	0.1113	27	23	24.2	24.0
925	50	0.0188	28	23	15.2	13.0
926	50	0.0342	28	23	17.8	17.5
927	50	0.0588	28	23	18.0	21.0
928	50	0.0934	28	23	26.6	28.0

Table 3M. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Tapered Wedge Gate Valve 1/4 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
929	2		19		0.1	
930	4		19		0.1	
931	6		19		0.2	
932	8		19		0.3	
933	10		19		0.4	
934	12		19		0.5	
935	14		19		0.6	
936	20		20		1.0	
937	30		20		2.2	
938	40		20		3.6	
939	50		20		5.4	
940	60		20		7.7	
941	2	0.0115	21	27	0.2	0.0
942	2	0.0215	21	27	0.4	0.0
943	2	0.0373	21	27	0.6	0.0
944	2	0.0617	21	27	0.9	0.0
945	2	0.0990	21	27	1.2	0.0
946	2	0.1020	21	27	1.8	0.0
947	4	0.0120	22	27	0.5	0.0
948	4	0.0225	22	27	0.9	0.0
949	4	0.0377	22	27	1.4	0.0
950	4	0.0620	22	27	1.8	0.0
951	4	0.0845	22	27	2.4	0.0
952	4	0.1025	27	27	2.8	0.0
953	8	0.0130	23	27	1.2	0.0
954	8	0.0230	23	27	1.6	0.5
955	8	0.0383	23	27	3.0	1.0
956	8	0.0630	23	27	4.0	2.0
957	8	0.0868	23	27	5.0	3.0
958	8	0.1030	25	27	5.7	3.5
959	10	0.0133	25	27	1.8	0.0
960	10	0.0230	25	27	2.4	0.5
961	10	0.0395	25	27	2.8	2.0
962	10	0.0795	25	27	5.1	3.5
963	10	0.0885	25	27	5.9	5.0
964	10	0.0975	25	27	6.3	5.0
965	14	0.0135	25	27	2.4	1.5
966	14	0.0240	25	27	3.6	2.0
967	14	0.0410	25	27	5.3	4.0
968	14	0.0685	25	27	6.7	5.0

Table 3M. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Tapered Wedge Gate Valve 1/4 Total Turns Closed

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
969	14	0.0910	25	27	7.9	5.5
970	14	0.1080	25	27	9.2	7.0
971	20	0.0143	26	27	3.8	2.0
972	20	0.0255	26	27	5.3	3.5
973	20	0.0442	26	27	7.3	8.0
974	20	0.0730	26	27	10.2	9.0
975	20	0.0945	26	27	10.8	10.0
976	20	0.1040	26	27	11.8	11.0
977	30	0.0155	27	28	6.3	5.5
978	30	0.0280	28	28	8.3	7.0
979	30	0.0487	28	28	11.4	10.0
980	30	0.0775	28	28	13.9	13.0
981	30	0.0995	28	28	16.6	16.0
982	40	0.0170	28	27	9.6	9.0
983	40	0.0308	28	27	11.6	10.5
984	40	0.0528	28	27	15.2	15.0
985	40	0.0850	28	27	18.6	20.0
986	40	0.1150	28	27	20.0	22.0
987	50	0.0180	28	27	12.5	12.0
988	50	0.0340	28	27	14.5	16.0
989	50	0.0583	28	27	18.6	20.0
990	50	0.0860	28	27	22.9	25.0

Table 3N. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Gate Valve, Tapered Wedge, Rising Stem, 3/4 Total Turns Closed.

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
991	2		17		0.0	
992	4		17		0.3	
993	6		17		0.4	
994	8		17		0.7	
995	10		17		1.0	
996	12		17		1.4	
997	13		18		1.9	
998	20		18		3.7	
999	30		19		8.1	
1000	40		19		14.5	
1001	50		19		22.4	
1002	60		20			
1003	55		20		27.2	
1004	2	0.0120	20	25	0.3	0.0
1005	2	0.0214	20	25	0.7	0.0
1006	2	0.0566	20	25	1.0	0.0
1007	2	0.0610	21	26	2.4	0.0
1008	2	0.0834	21	26	3.8	0.7
1009	2	0.0906	21	26	4.8	1.5
1010	4	0.0124	21	26	0.9	0.0
1011	4	0.0224	21	26	1.2	0.0
1012	4	0.0363	21	26	2.3	0.0
1013	4	0.0614	21	26	3.8	1.0
1014	4	0.0842	21	26	5.3	2.0
1015	4	0.1015	21	26	6.7	3.0
1016	8	0.0126	22	26	2.8	0.0
1017	8	0.0225	22	26	3.6	2.0
1018	8	0.0385	22	26	4.8	2.5
1019	8	0.0641	23	26	6.7	5.0
1020	8	0.0873	23	26	9.2	6.0
1021	8	0.1063	23	26	11.0	7.0
1022	10	0.0132	23	26	4.2	1.5
1023	10	0.0233	23	26	5.1	2.5
1024	10	0.0406	23	26	5.9	3.5
1025	10	0.0641	23	26	9.1	5.0
1026	10	0.0897	23	26	11.2	7.5
1027	10	0.1063	23	26	13.3	9.0
1028	14	0.0137	24	26	5.7	3.5
1029	14	0.0244	24	26	7.7	5.0
1030	14	0.0478	24	26	9.6	6.0

Table 3N. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Gate Valve, Tapered Wedge, Rising Stem, 3/4 Total Turns Closed.

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
1031	14	0.0696	24	26	12.5	9.0
1032	14	0.0932	24	26	15.7	12.0
1033	14	0.1100	24	26	18.1	13.0
1034	20	0.0143	24	26.0	9.6	16.0
1035	20	0.0263	24	26.0	11.8	17.0
1036	20	0.0518	24	26.0	15.3	11.0
1037	20	0.0747	24	26.0	19.7	15.0
1038	20	0.0955	24	26.0	23.3	17.0
1039	30	0.0180	25	26	18.3	11.5
1040	30	0.0305	25	26	20.6	15.0
1041	30	0.0612	25	26	26.6	20.0
1042	30	0.0844	25	26	29.0	26.0
1043	40	0.0190	26	26	28.2	20.0
1044	40	0.0079	26	26	26.8	17.0
1045	40	0.0056	26	26	23.2	14.2
1047	45	0.0056	26	26	28.0	18.5
1048	45	0.0080	22	26	29.2	19.0

Table 30. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Standard 90° Elbows

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
1094	4		24		0.4	
1095	6		24		0.4	
1096	8		24		0.6	
1097	10		24		0.7	
1098	14		24		1.0	
1099	20		24		2.9	
1100	30		24		4.5	
1101	40		24		7.2	
1102	50		24		10.3	
1103	60		24		15.6	
1104	4	0.0083	24	25	1.6	0.0
1105	4	0.0175	25	25	2.0	0.0
1106	4	0.0365	25	25	2.4	0.0
1107	4	0.0505	25	25	2.6	0.5
1108	4	0.0692	25	25	3.6	1.3
1109	4	0.0860	25	25	3.9	1.8
1110	6	0.0087	25	25	2.4	0.0
1111	6	0.0178	25	25	3.0	0.3
1112	6	0.0370	25	25	3.6	1.4
1113	6	0.0570	25	25	4.7	2.8
1114	6	0.0875	25	25	6.7	3.5
1115	8	0.0087	25	25	3.8	0.9
1116	8	0.0182	25	25	3.4	1.1
1117	8	0.0376	25	25	5.1	3.5
1118	8	0.0533	26	25	6.7	3.1
1119	8	0.0658	26	25	7.1	4.1
1120	8	0.0887	26	25	8.5	5.1
1121	10	0.0088	26	26	3.8	1.2
1022	10	0.0187	26	26	4.7	2.1
1023	10	0.0382	26	26	6.3	3.7
1024	10	0.0675	26	26	9.6	5.9
1125	10	0.0903	26	26	12.0	7.5
1126	14	0.0090	26	26	4.2	2.1
1127	14	0.0195	26	26	6.3	3.1
1128	14	0.0410	26	26	9.8	5.6
1129	14	0.0705	26	26	14.3	9.3
1130	14	0.0934	26	26	17.4	11.3
1131	20	0.0095	26	26	6.9	4.1
1132	20	0.0209	26	26	9.2	5.4
1133	20	0.0447	26	26	14.3	8.9
1134	20	0.0765	26	26	19.7	13.0

Table 30. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Standard 90° Elbows

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	$P_{inlet\ to}$ Test Section psig.
1135	20	0.0937	26	26	24.2	16.3
1136	30	0.0103	26	26	11.2	7.9
1137	30	0.0234	26	26	15.9	10.9
1138	30	0.0563	26	26	23.8	17.5
1139	30	0.0835	26	26	27.4	21.8
1140	30	0.1230	26	26	29.4	26.2
1141	40	0.0117	27	27	15.9	11.5
1142	40	0.0263	27	27	23.0	17.0
1143	40	0.0560	27	27	24.2	24.5
1144	40	0.0500	27	27	29.2	24.0
1145	40	0.0434	27	27	27.8	22.0
1146	50	0.0100	27	27	20.2	15.6
1147	50	0.0170	27	27	22.4	17.0
1148	50	0.0280	27	27	28.0	22.0

Table 3P. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Standard Tee, Side Inlet

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
1193	4		25	27	0.0	
1194	6		25	27	0.2	
1195	8		25	27	0.3	
1196	10		25	29	0.5	
1197	14		25	29	1.0	
1198	20		25	29	2.0	
1199	30		25	29	4.1	
1200	40		25	29	8.8	
1201	50		25	29	13.5	
1149	4	0.0085	25	29	1.2	0.0
1150	4	0.0126	25	29	1.4	0.0
1151	4	0.0336	25	29	1.8	0.5
1152	4	0.0510	26	29	2.6	0.5
1153	4	0.0764	26	29	4.0	1.5
1154	6	0.0085	26	29	2.0	0.0
1155	6	0.0179	26	29	2.4	0.5
1156	6	0.0361	26	29	3.5	1.7
1157	6	0.0516	26	29	5.3	2.5
1158	6	0.0796	26	24	7.1	4.0
1159	8	0.0086	26	29	2.2	0.5
1160	8	0.0184	26	29	3.3	1.5
1161	8	0.0384	26	29	5.5	1.8
1162	8	0.0543	26	29	7.7	9.2
1163	8	0.0816	26	29	10.4	6.2
1164	10	0.0087	26	29	3.0	1.5
1165	10	0.0184	27	29	4.3	2.5
1166	10	0.0394	27	29	8.4	4.5
1167	10	0.0554	27	29	10.7	6.0
1168	10	0.0839	27	29	13.7	9.0
1169	14	0.0088	27	29	4.7	2.5
1170	14	0.0194	28	29	7.5	4.5
1171	14	0.0414	28	29	12.5	7.0
1172	14	0.0590	28	29	16.0	10.0
1173	14	0.0836	28	29	19.8	12.5
1174	20	0.0096	28	29	7.8	5.0
1175	20	0.0209	28	29	11.3	7.0
1176	20	0.0393	29	29	17.4	10.5
1177	20	0.0604	29	29	23.0	14.0
1178	20	0.0851	29	29	27.6	18.0
1179	30	0.0106	29	29	14.4	9.0
1180	30	0.0236	29	29	19.4	12.5

Table 3P. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Standard Tee, Side Inlet

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
1181	30	0.0447	29	29	26.8	19.0
1182	30	0.0480	29	29	27.6	20.0
1183	30	0.0341	29	29	23.6	15.5
1184	40	0.0080	30	30	18.8	12.0
1185	40	0.0141	30	30	22.2	15.5
1186	40	0.0214	30	30	25.8	17.5
1187	40	0.0266	30	30	28.6	20.0
1188	40	0.0214	30	30	27.2	18.5
1189	50	0.0060	30	30	23.8	16.5
1190	50	0.0085	30	30	25.4	17.0
1191	50	0.0110	30	30	27.4	18.5
1192	50	0.0130	30	30	28.2	19.5

Table 3Q. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Long Turn 90° Elbows

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
1202	4		25		0.1	
1203	6		26		0.2	
1204	8		26		0.4	
1205	10		26		0.6	
1206	14		26		0.9	
1207	20		26		1.9	
1208	30		26		3.9	
1209	40		26		7.1	
1210	50		26		10.5	
1211	4	0.0080	26	25	1.2	0.0
1212	4	0.0177	27	25	1.4	0.0
1213	4	0.0362	27	25	2.1	0.0
1214	4	0.0626	27	25	3.3	1.0
1215	4	0.0860	27	25	4.3	2.0
1216	6	0.0083	28	25	1.4	0.0
1217	6	0.0175	28	25	1.9	0.6
1218	6	0.0361	28	25	2.7	1.5
1219	6	0.0654	28	25	5.4	3.0
1220	6	0.0874	28	25	6.9	3.5
1221	8	0.0086	28	26	2.3	0.5
1222	8	0.0186	28	26	3.3	0.8
1223	8	0.0374	28	26	5.3	2.0
1224	8	0.0662	28	26	7.5	4.5
1225	8	0.0884	28	26	9.6	6.0
1226	10	0.0086	29	26	2.8	0.5
1227	10	0.0184	29	26	3.7	1.2
1228	10	0.0387	29	26	6.7	4.0
1229	10	0.0675	29	26	10.0	6.2
1230	10	0.0910	29	26	12.1	7.8
1231	14	0.0087	29	26	3.7	1.0
1232	14	0.0194	29	26	5.9	3.0
1233	14	0.0404	29	26	9.6	5.0
1234	14	0.0677	29	26	13.7	9.0
1235	14	0.0912	29	26	16.6	11.0
1236	20	0.0097	29	26	6.0	4.0
1237	20	0.0202	29	26	8.6	5.5
1238	20	0.0446	29	26	14.4	10.0
1239	20	0.0625	29	26	19.6	12.5
1240	20	0.0923	29	26	23.8	17.0
1241	30	0.0104	30	26	11.1	7.4
1242	30	0.0228	30	26	14.4	10.0

Table 3Q. Data for Co-Current Flow of Air and Water in 1 1/2 Inch Test Section 338 Inches Long - Long Turn 90° Elbows

Run No.	Q_L GPM.	W_G lb./sec.	T_L °C	T_G °C	$(\Delta P)_{exp.}$ in.Hg.	P_{inlet} to Test Section psig.
1243	30	0.0439	30	26	21.0	15.0
1244	30	0.0559	30	26	23.8	18.0
1245	30	0.0822	30	26	27.2	21.5
1246	40	0.0114	30	26	16.2	11.0
1247	40	0.0230	30	26	20.6	15.5
1248	40	0.0441	30	26	27.0	20.5
1249	40	0.0484	30	27	28.0	23.0
1250	40	0.0337	30	27	24.1	19.0
1251	50	0.0124	30	27	21.6	16.0
1252	50	0.0222	30	27	25.6	19.0
1253	50	0.0281	30	27	28.0	22.0
1254	50	0.0250	30	27	27.6	21.5
1255	50	0.0176	30	27	23.8	19.0

APPENDIX III-A

SAMPLE CALCULATIONS

Co-current Flow of Air and Water in 1 1/2 Inch Test Section Without Valve. Run No. 150 (Table 1)

The pressure drop over the 338 inch test section was determined from the output pressure of the differential transmitter and found to be

$$\Delta P_{TP-EXP} = 10.1 \text{ in.Hg.}$$

Calculation of a superficial liquid pressure drop per unit length that is the loss that would occur if the liquid phase were flowing along in the pipe.

Water flow rate = 40 GPM

Water temperature = 25° C

Water viscosity (17) = $6.01 \times 10^{-4} \dfrac{\text{lb.mass}}{\text{ft.sec.}} = \mu_L$

Water density (18) = $62.24 \dfrac{\text{lb}_{\text{m.}}}{\text{ft.}^3} = \rho_L$

The pounds of water flowing per second was found to be

$$W_L = \frac{40(231)\ 62.24}{1728\ (60)} = 5.55 \text{ lb.mass/sec.}$$

Using these values the Reynolds number was computed.

$$Re_L = \frac{4W_L}{\pi D \mu_L} = \frac{4\ (5.55)}{3.14\ (1.5/12)\ 6.01 \times 10^{-4}} = 9.40 \times 10^4$$

From this Reynolds number and the Nikuradse friction factor equation the friction factor was calculated.

$$\frac{1}{\sqrt{f_L}} = 2\log_{10}\left(Re\sqrt{f_L}\right) - 0.8 = 2\log_{10}\left(9.40\times10^4\sqrt{f_L}\right) - 0.8;\ f_L = 0.0183$$

The calculated superficial pressure drop per unit length was found to be

$$\left(\frac{\Delta P}{\Delta L}\right)_L = \frac{f_L W_L^2}{2g_c\ DA^2\rho_L} = \frac{0.0183\ (5.55)^2}{2(32.2)\ \frac{1.5}{12}\left(\frac{\pi}{4}\right)\left(\frac{1.5}{12}\right)^2 62.24\ (144)}$$

$$\left(\frac{\Delta P}{\Delta L}\right)_L = 5.16\times10^{-2}\ \text{psi./ft.}$$

Calculation of superficial gas pressure drop.

The air rate was calculated from the rotameter reading with the manufacturer's calibration and the appropriate temperature and pressure correction applied and found to be

$W_G = 0.0290$ lb.mass/sec.

Air temperature = 25°C

Air viscosity (19) = $0.1231\times10^{-4}\ \frac{\text{lb.mass}}{\text{ft.sec.}} = \mu_G$

Using these values the Reynolds number was computed.

$$Re_G = \frac{4W_G}{\pi D\mu_G} = \frac{4\ (0.0290)}{3.1416\left(\frac{1.5}{12}\right)0.1231\times10^{-4}} = 2.40\times10^4$$

The Re_G value and the Nikuradse equation were used for the friction factor.

$$\frac{1}{\sqrt{f_G}} = 2\log_{10}\left(2.40\times10^4\sqrt{f_G}\right) - 0.8$$

$$f_G = 0.0248$$

The pressure at the upstream pressure pick-up was measured on a Bourdon gage and found to be 25.7 psia. and the average pressure in the test section was approximated as

$$P_{AVG} = P_{UP\text{-}STREAM} - \frac{0.4895(\Delta P)exp}{2}$$

$$P_{AVG} = 25.7 - \frac{0.4895(10.1)}{2} = 23.2 \text{ psia.}$$

The calculated superficial pressure drop per unit length was found to be

$$\left(\frac{\Delta P}{\Delta L}\right)_G = \frac{1.162 \times 10^3 \ f_G W_G^2}{P_{AVG}}$$

$$\left(\frac{\Delta P}{\Delta L}\right)_G = \frac{1.162 \times 10^3 \ (0.0248) \ (0.0290)^2}{23.2} = 10.44 \times 10^{-4} \ \frac{\text{psi.}}{\text{ft.}}$$

The X^2 term in Lockhart and Martinelli (1) correlation was next evaluated.

$$X^2 = \frac{(\Delta P/\Delta L)_L}{(\Delta P/\Delta L)_G} = \frac{5.16 \times 10^{-2}}{10.44 \times 10^{-4}} = 49.43$$

The Lockhard and Martinelli ϕ^2_{LTT} term was found to be

$$\phi^2_{LTT} = \frac{(\Delta P/\Delta L)_{TP}}{(\Delta P/\Delta L)_L} = \frac{\Delta P_{TP\text{-}EXP.}}{2.035 \ (28.17) \ (5.16 \times 10^{-2})}$$

$$\phi^2_{LTT} = \frac{10.1}{2.035 \ (28.17) \ (5.040 \times 10^{-2})} = 3.42$$

These values were then plotted in fig. 10 to illustrate the agreement with the curve of Lockhart and Martinelli (1).

APPENDIX III-B

SAMPLE CALCULATIONS

Calculation of Single-Phase Equivalent Length Multiplying Factor, Ψ, for Composition Disc Valve, Full Open.
Run 252 (Table 2-A)

The pressure drop over the 338 inch test section was determined from the output of the differential manometer and found to be

$$\Delta P_{TP-EXP} = 10.0 \text{ in.Hg.}$$

Calculation of a superficial liquid phase pressure drop per unit length, that is the pressure loss that would occur if the water were flowing alone was computed exactly as in Appendix III-A and found to be

$$\left(\frac{\Delta P}{\Delta L}\right)_L = 300.93 \times 10^{-4} \text{ psi./ft.}$$

Calculation of a superficial gas phase pressure drop was determined exactly as in Appendix III-A and found to be

$$\left(\frac{\Delta P}{\Delta L}\right)_G = 4.44 \times 10^{-4} \text{ psi./ft.}$$

The X^2 value used by Lockhart and Martinelli (1) was found to be

$$X^2 = \frac{(\Delta P/\Delta L)_L}{(\Delta P/\Delta L)_G} = \frac{300.93 \times 10^{-4}}{4.44 \times 10^{-4}} = 67.78$$

From the curve on fig. 23 the value of Φ^2 corresponding an X^2 of 67.78 was found to be

$$\Phi^2_{LTT} = 3.39$$

The two-phase pressure drop per unit length was found to be

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP-MART} = \Phi^2_{LTT} \left(\frac{\Delta P}{\Delta L}\right)_L = 3.39\ (300.93 \times 10^{4}) = 0.102 \text{ psi./ft.}$$

The mass flow ratio was computed from a chart of air rate versus mass flow ratio with the parameter of constant water rates. The ratio was found to be

$$W_L / W_G = 255$$

The equation for calculation Ψ was gotten as follows. A value for the L/D ratio of 330 was found for this valve (19). The L/D for the straight 1 1/2 inch I.D. pipe section 338 inches long was found to be 225.

$$\left(\frac{\Delta P}{\Delta L}\right)_{TP-MART} \left[\frac{225(1.5)}{12} + \Psi \frac{(330)(1.5)}{12}\right] 2.035 = \Delta P_{TP-EXP}$$

Thus $$\Psi = \frac{0.0119 \quad \Delta P_{TP-EXP}}{\left(\frac{\Delta P}{\Delta L}\right)_{TP-MART}} - 0.682$$

$$\Psi = \frac{0.0119(10.0)}{0.102} - 0.628 = 0.485$$

The value of Ψ with its corresponding value of W_L/W_G was plotted to aid in constructing the curve found in fig. 22.

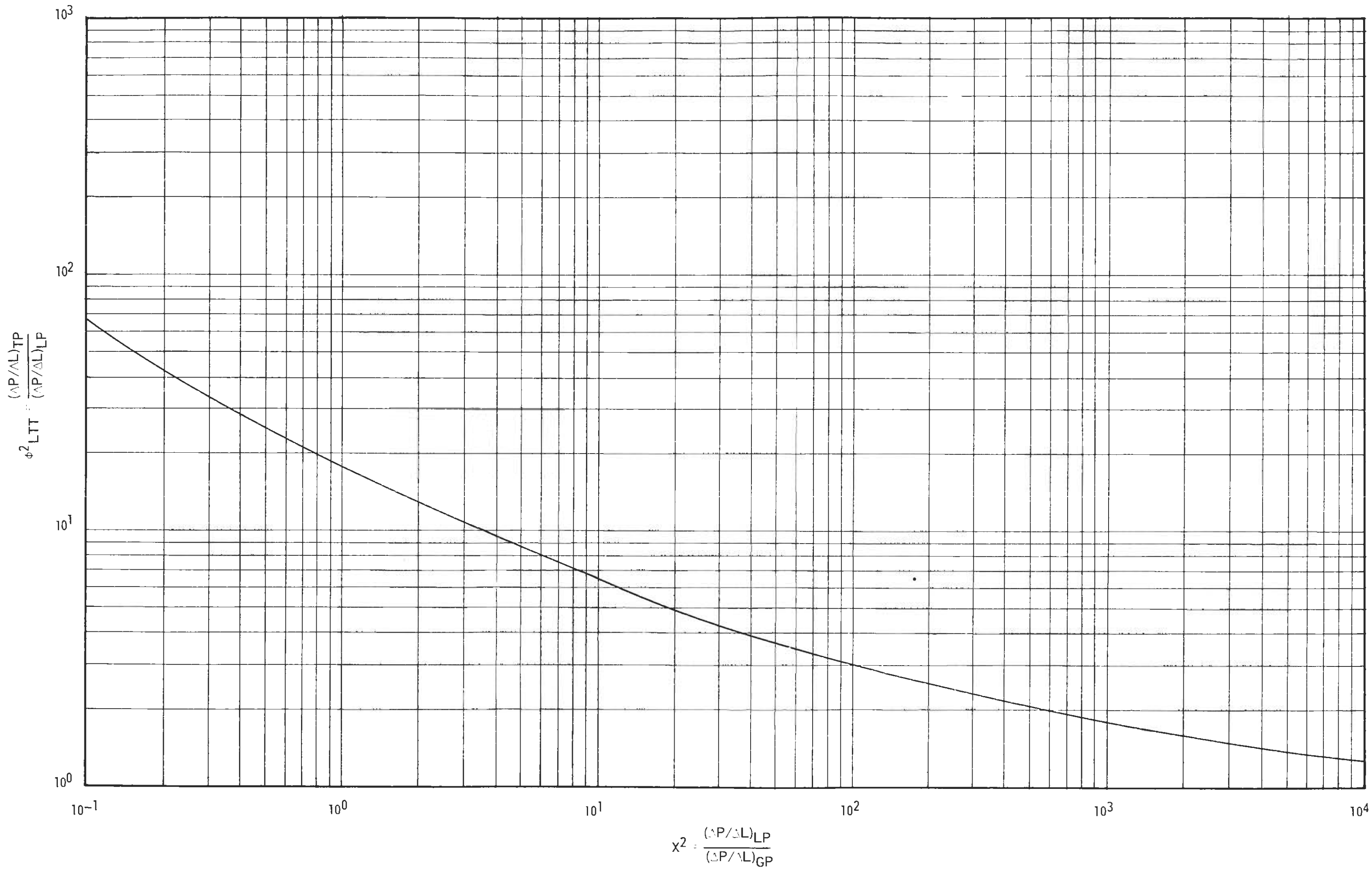


Figure 23. Correlation Curves from Data of Lockhart and Martinelli (1) for Co-current Turbulent - Turbulent Gas-liquid Flow in Cylindrical Tubes.

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